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Towards net zero: harnessing the “hidden”
energy of latent heat

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Towards net zero: harnessing the “hidden” energy of latent heat

A brief overview of some contributions towards understanding and implementing flow-based phase change processes, and phase change energy storage mechanisms, and a forward view of opportunities.



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From Hot Coffee to Hidden Power

Sensible heat



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From Hot Coffee to Hidden Power

Latent heat



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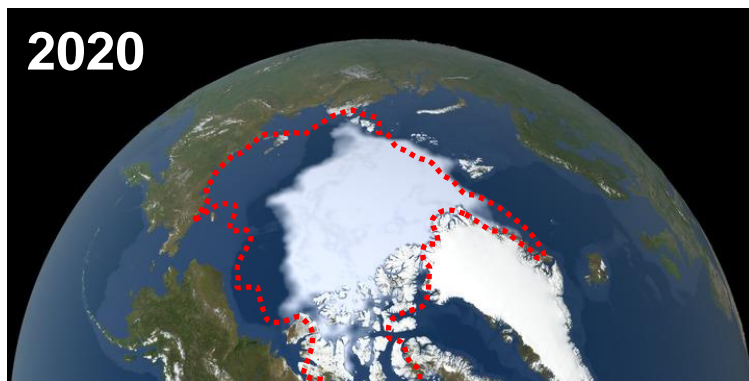
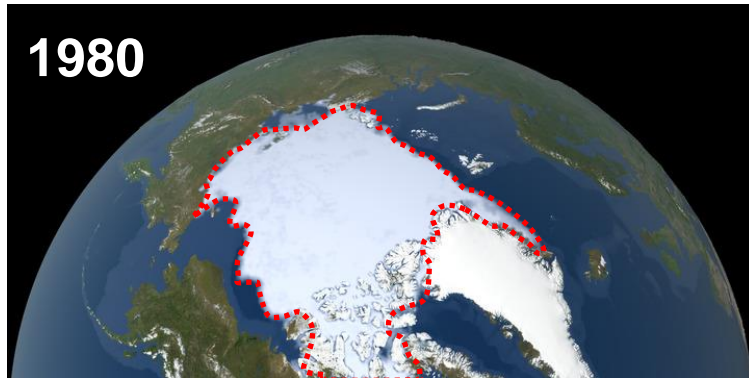
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The Modern Energy Challenge

Global environmental changes

Arctic sea ice minimum extent



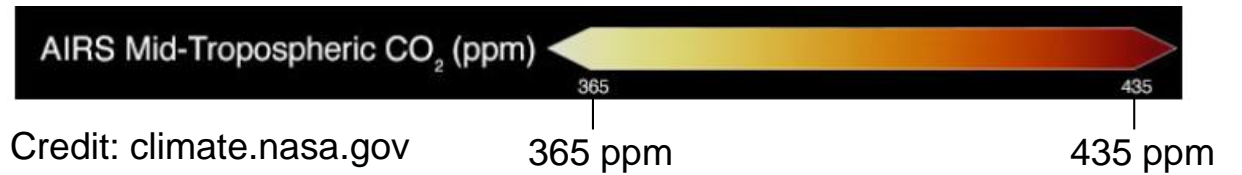
Credit: climate.nasa.gov

Global CO₂

2002



2022



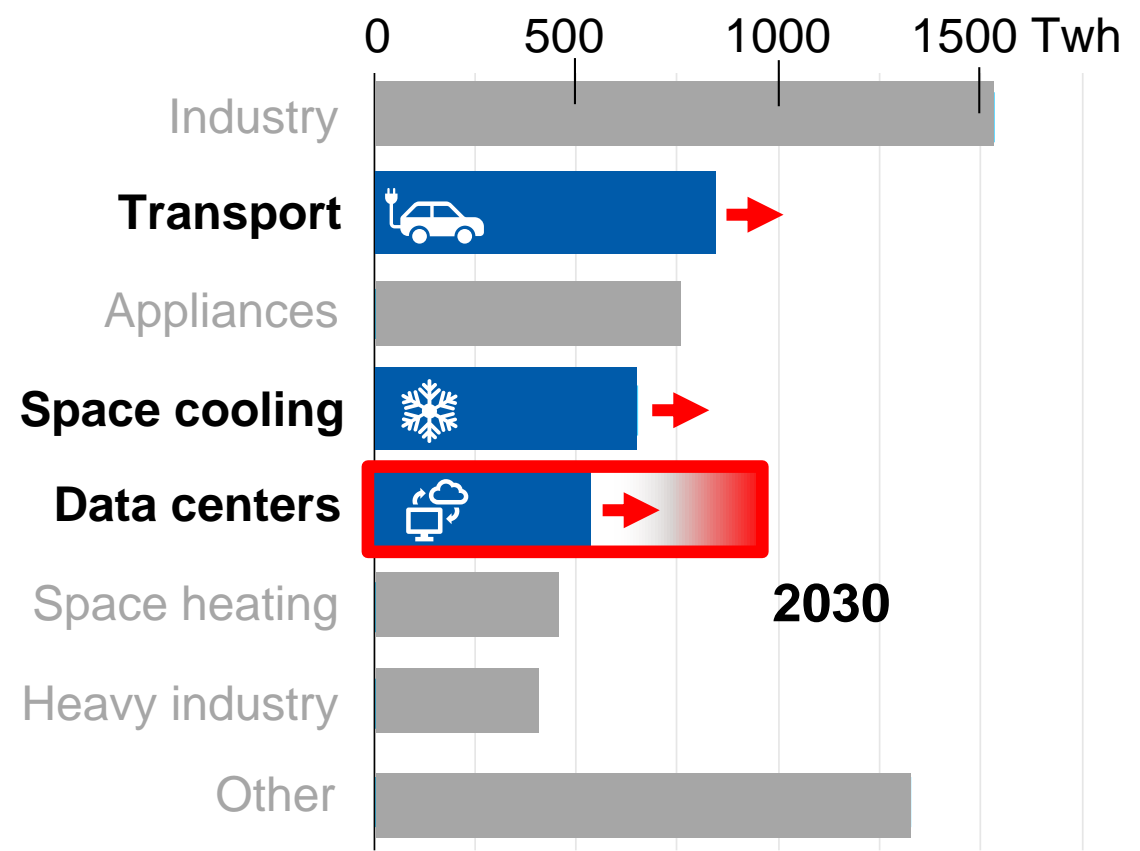
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The Modern Energy Challenge

Energy consumption shift

2025 Global electricity consumption



Data: iea.org

Data centers



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Harnessing Latent Heat: Solutions and Applications

- Passive thermal storage
- Active heat transport



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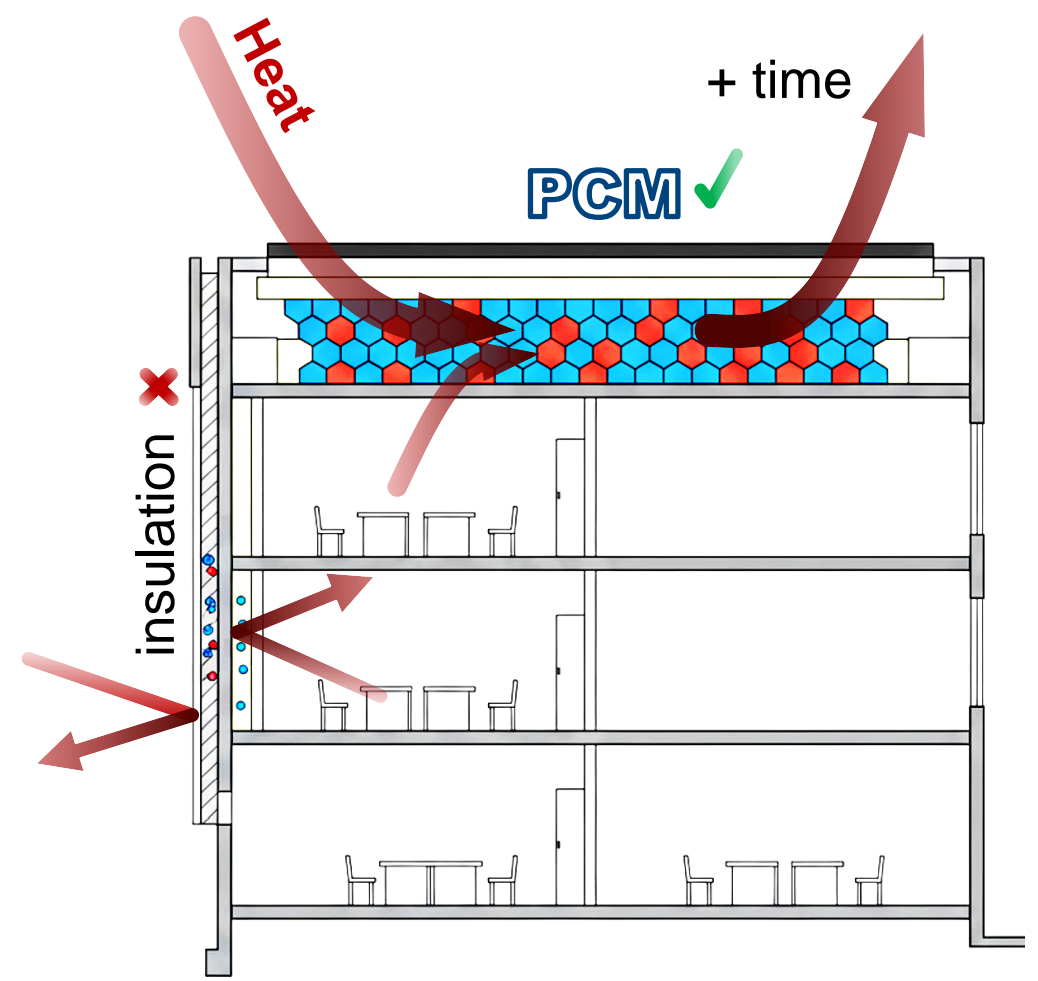
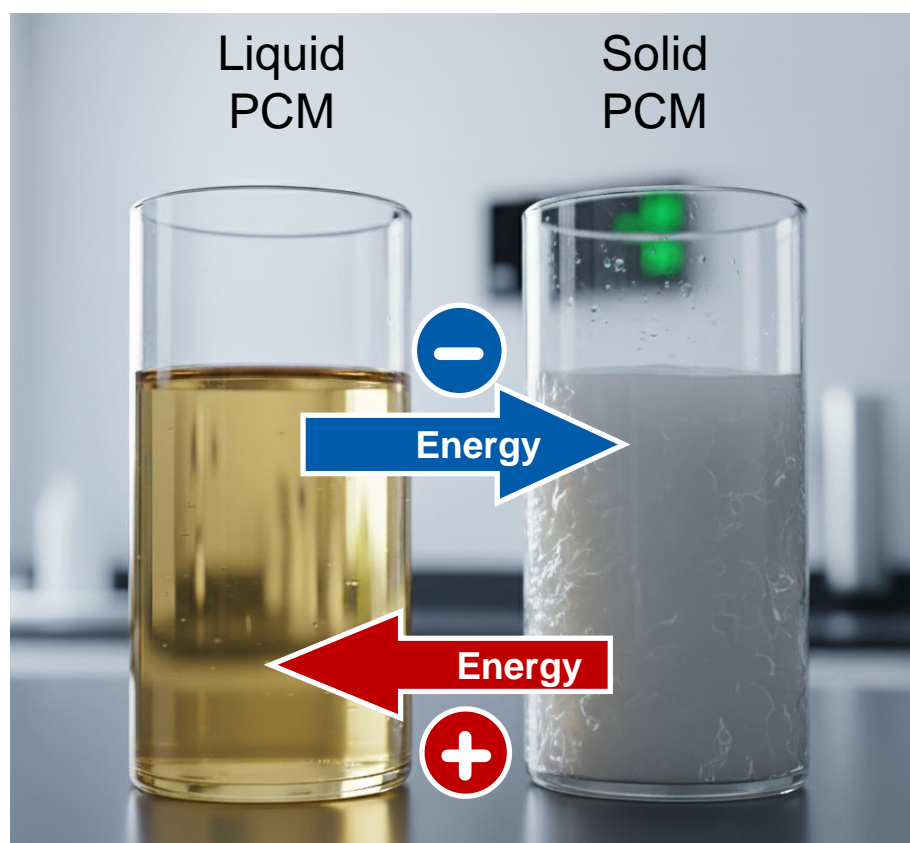
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Harnessing Latent Heat: Solutions and Applications

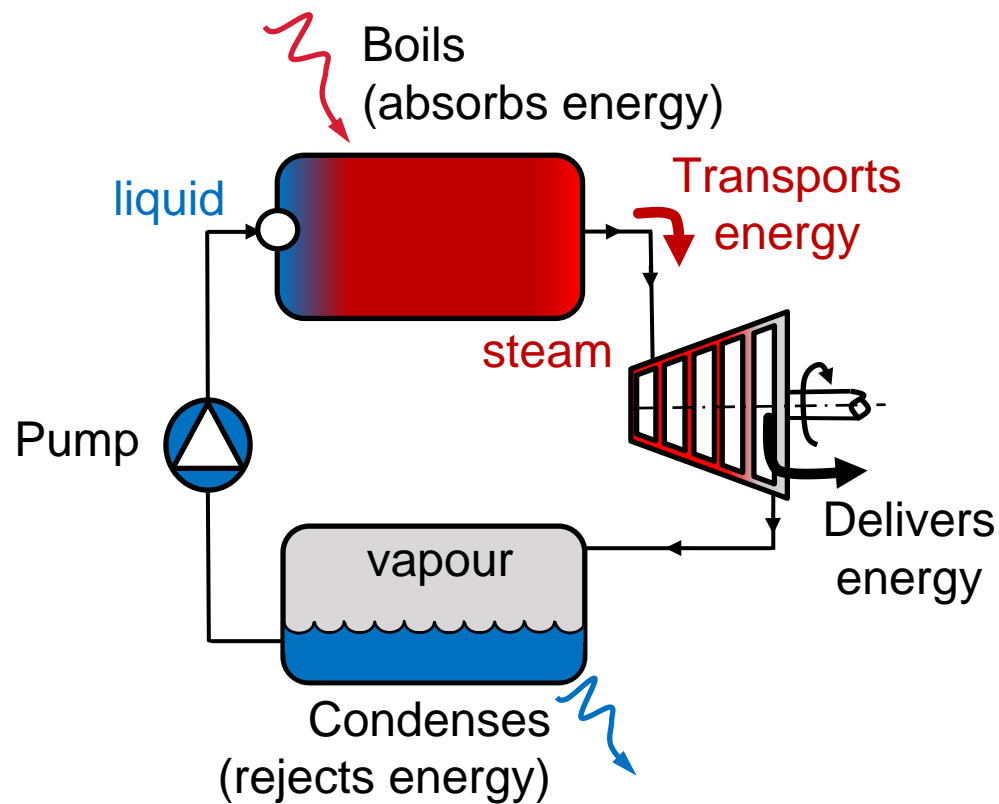
Passive thermal storage



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Harnessing Latent Heat: Solutions and Applications

Active heat transport: Thermodynamic cycles
Power production



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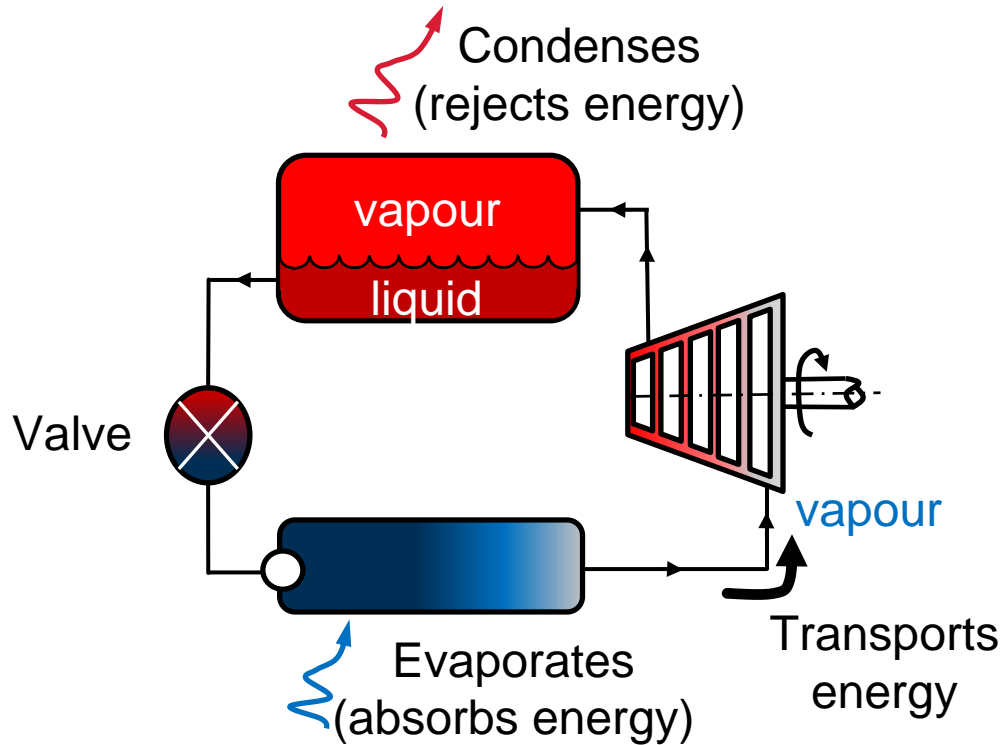
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Harnessing Latent Heat: Solutions and Applications

Active heat transport: Thermodynamic cycles Refrigeration and air conditioning



Front



Rear



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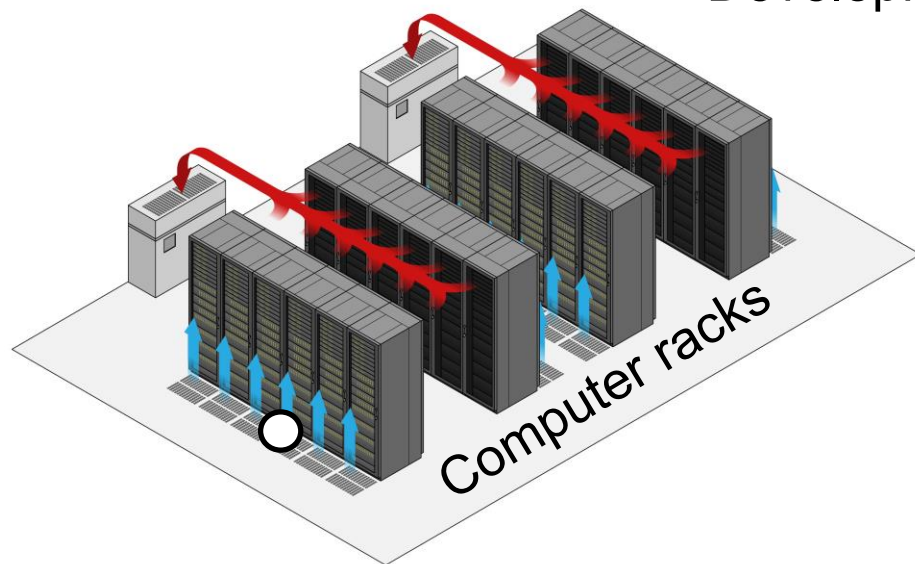
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Harnessing Latent Heat: Solutions and Applications

Active heat transport: Thermodynamic cycles

High density cooling

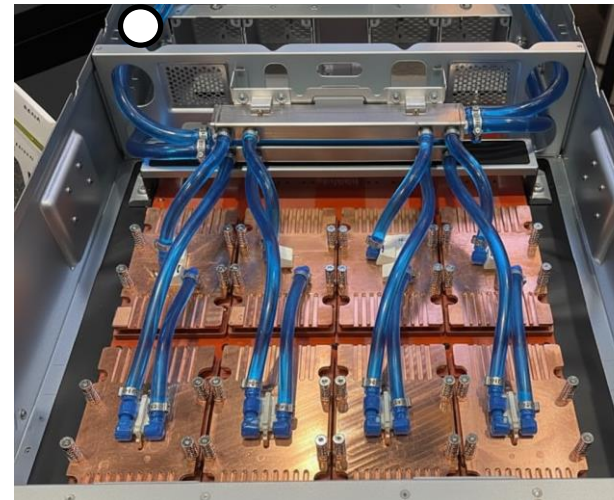
Air-cooled
Gas only



→
Development

Liquid-cooled

Boiling at the processor?



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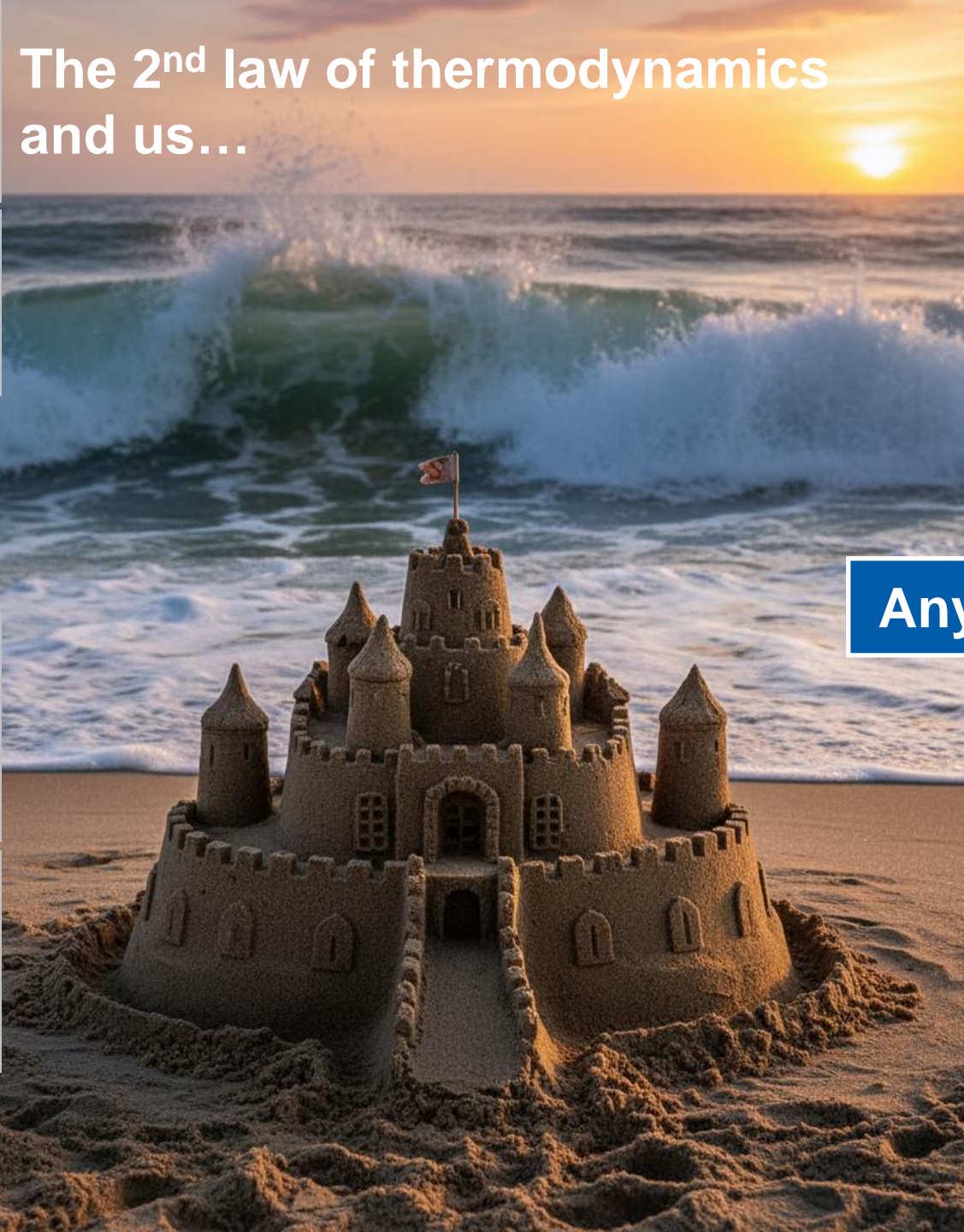
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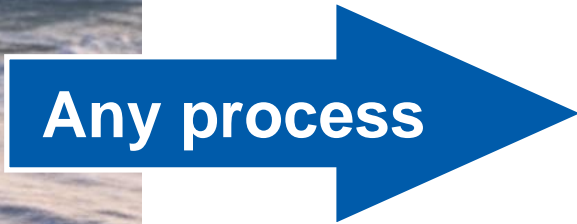
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The 2nd law of thermodynamics and us...



The Unseen Cost of Energy: Entropy



Any process

Entropy generation



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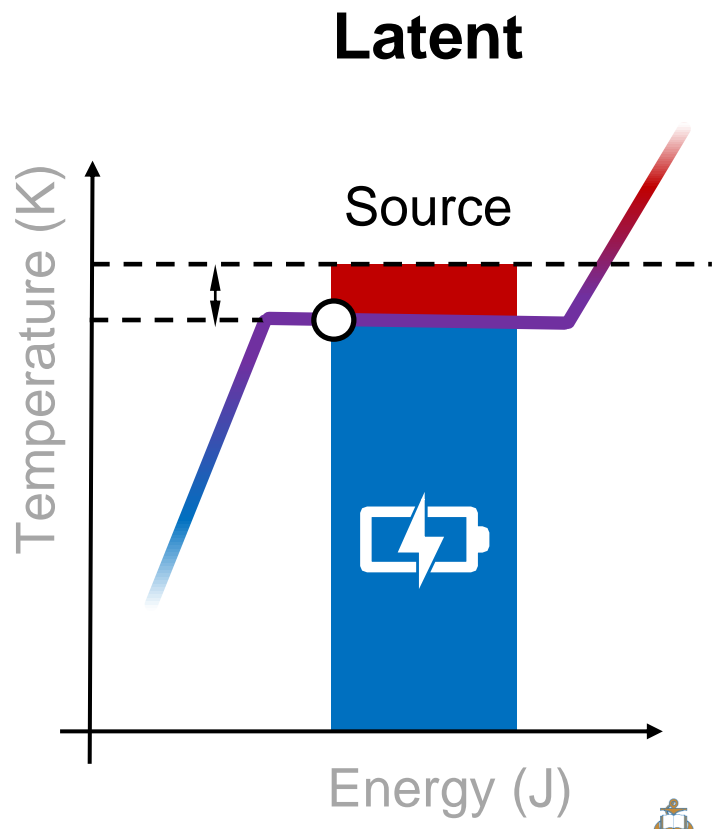
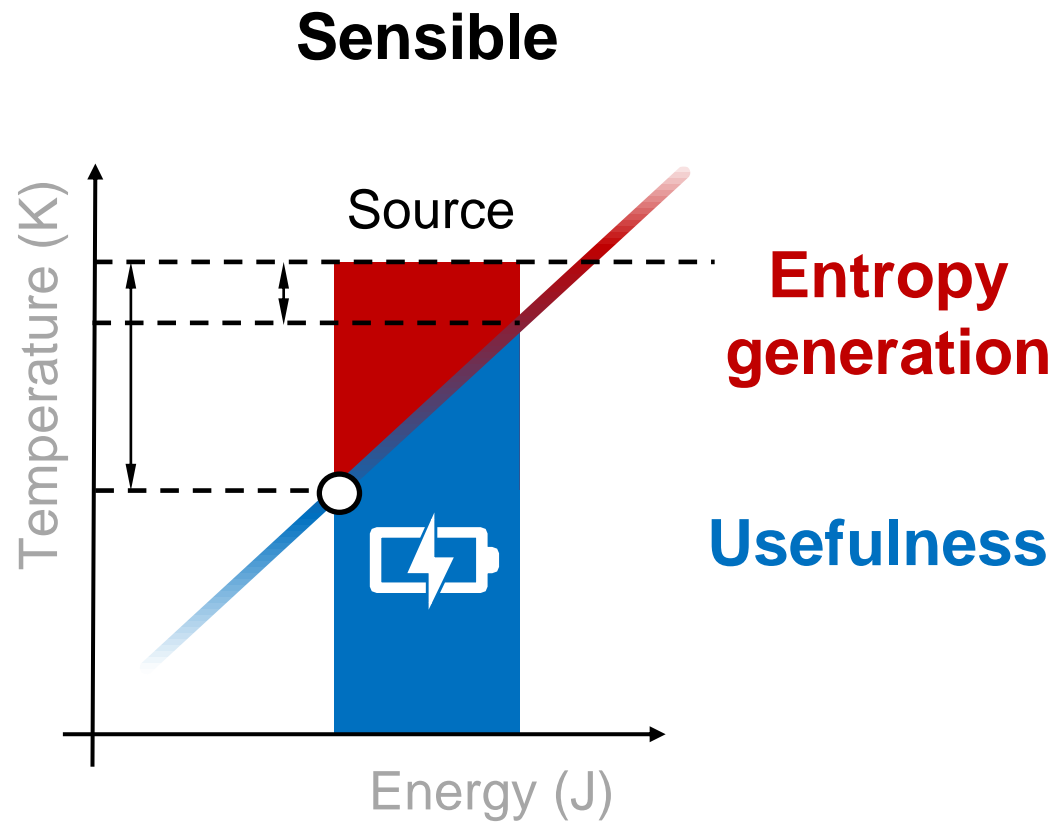
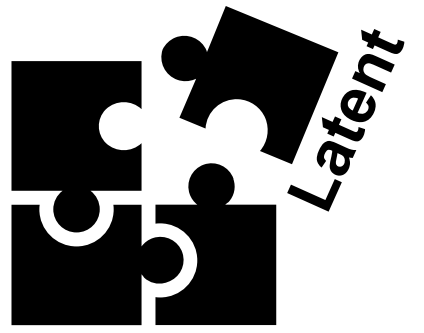
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Latent Heat: The Efficiency Expert



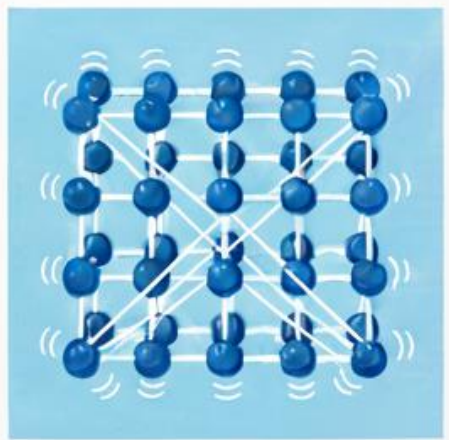
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The Physics Behind the Change: A Molecular Perspective

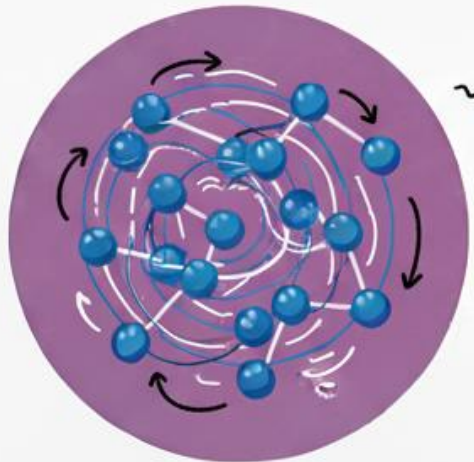
Solid

A structured dance



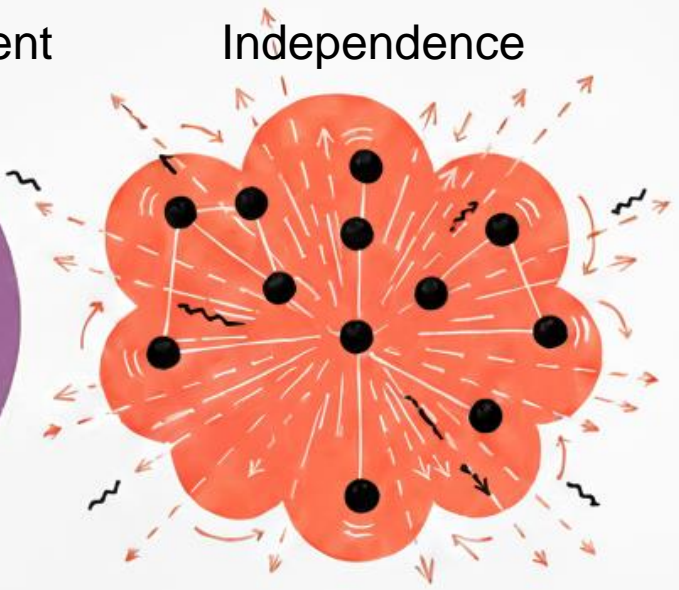
Liquid

Freedom of Movement



Vapour

Independence



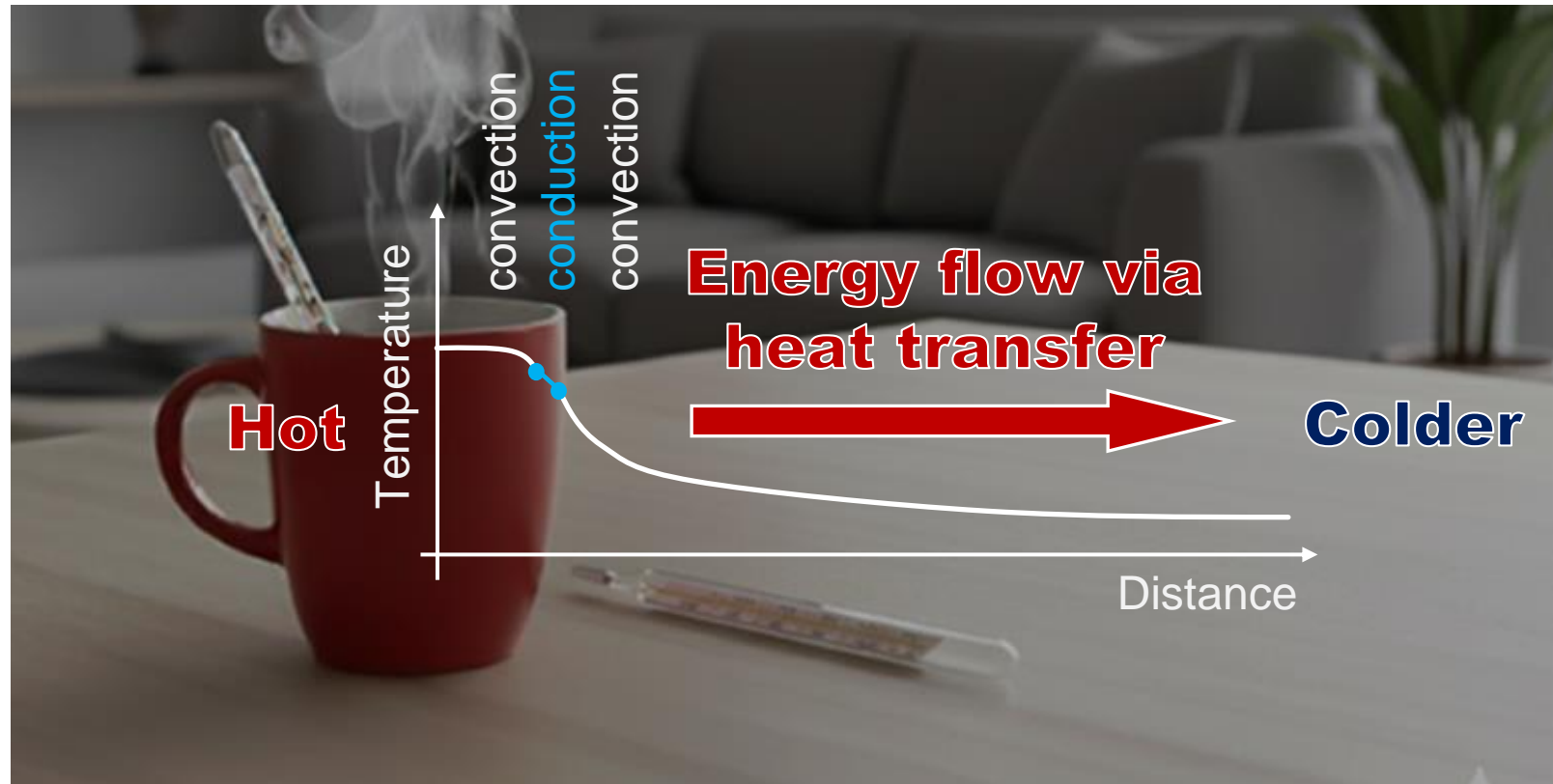
Energy content



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Thermal Mechanisms: The Role of Heat



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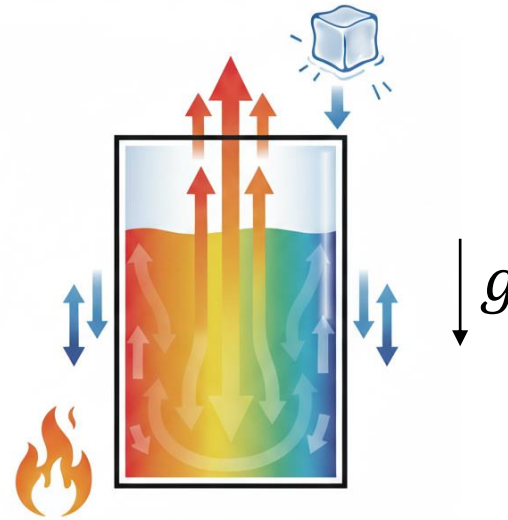
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Heat Transfer Mechanisms: From Weak to Powerful

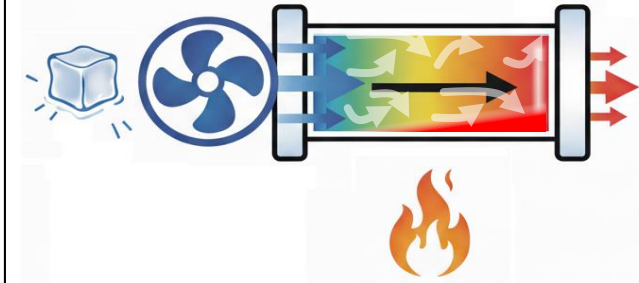
Conduction



Natural convection



Forced convection



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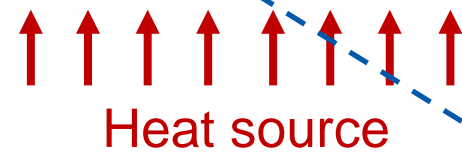
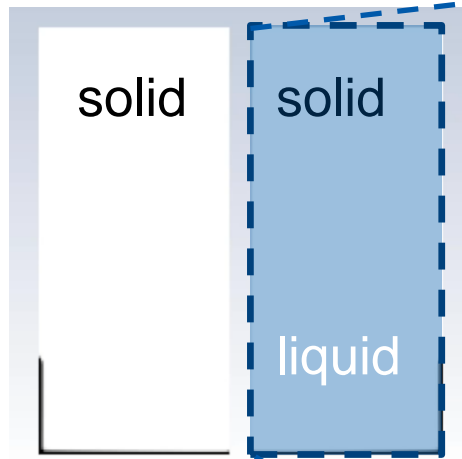
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Fluid Dynamics: All about Motion

Natural convection with melting & solidification

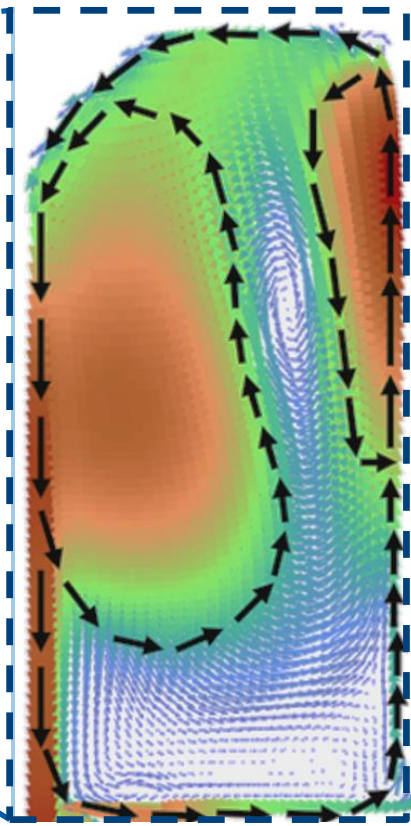
Cylindrical solid melting
simulation



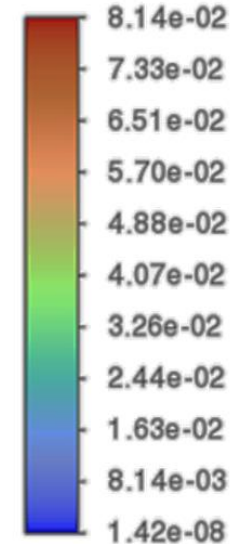
□ = solid

■ = liquid

Velocities



Velocity Magnitude
[m/s]



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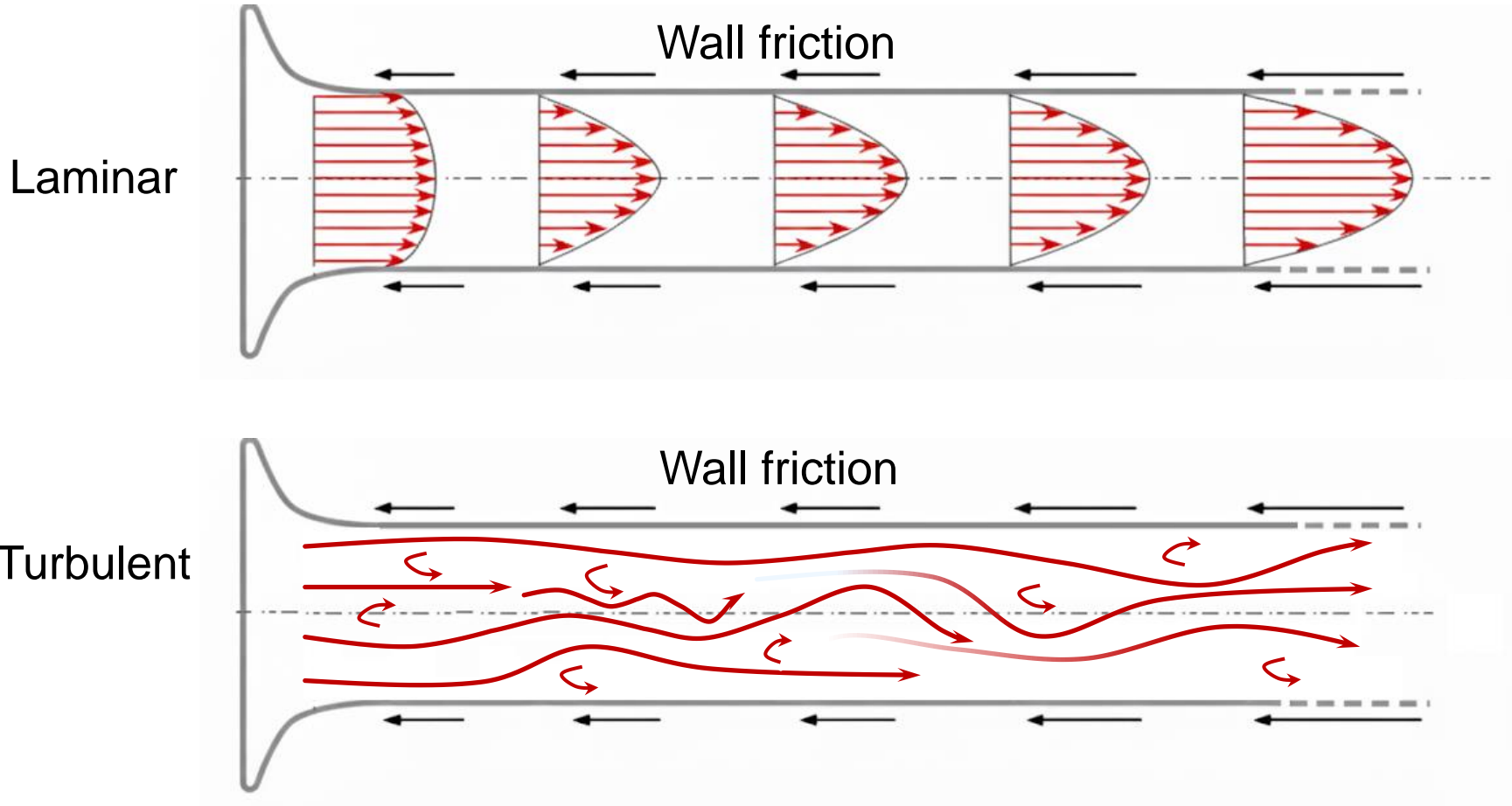
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Fluid Dynamics: All about Motion

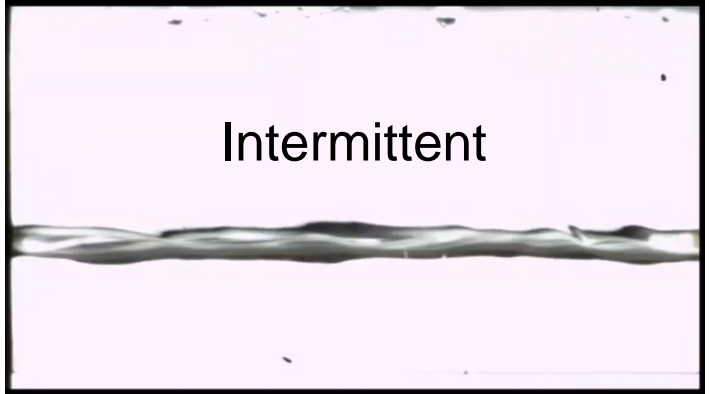
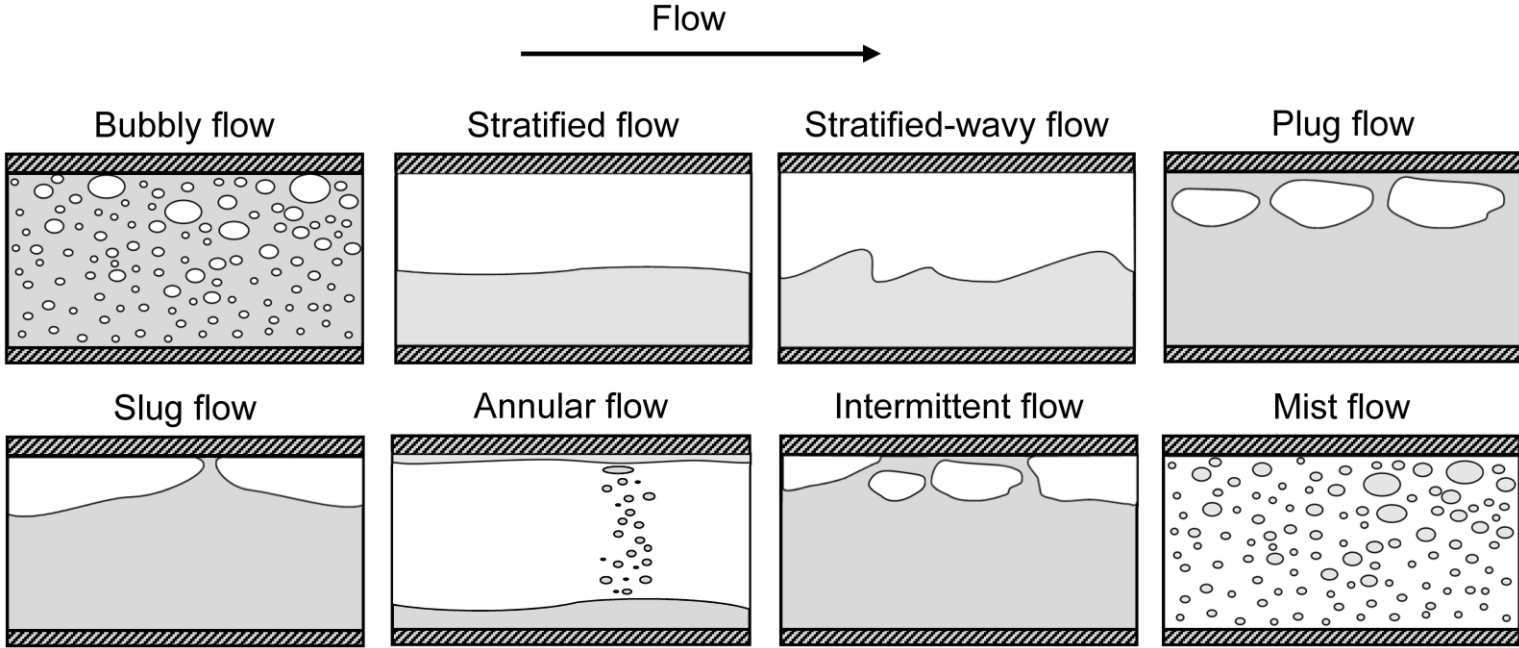
Forced convective flows



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Fluid Dynamics: All about Motion

Two-phase flows



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Some Recent and Current Focus Areas

Active heat transport

- Macro scale flow boiling
- Macro scale condensation
- Miniature scale flow boiling



Passive thermal storage

- High-temperature
- Medium-temperature



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Macro Scale Flow Boiling

Concentrated Solar Power: Direct Steam Generation



Stock photographs



Stock photographs



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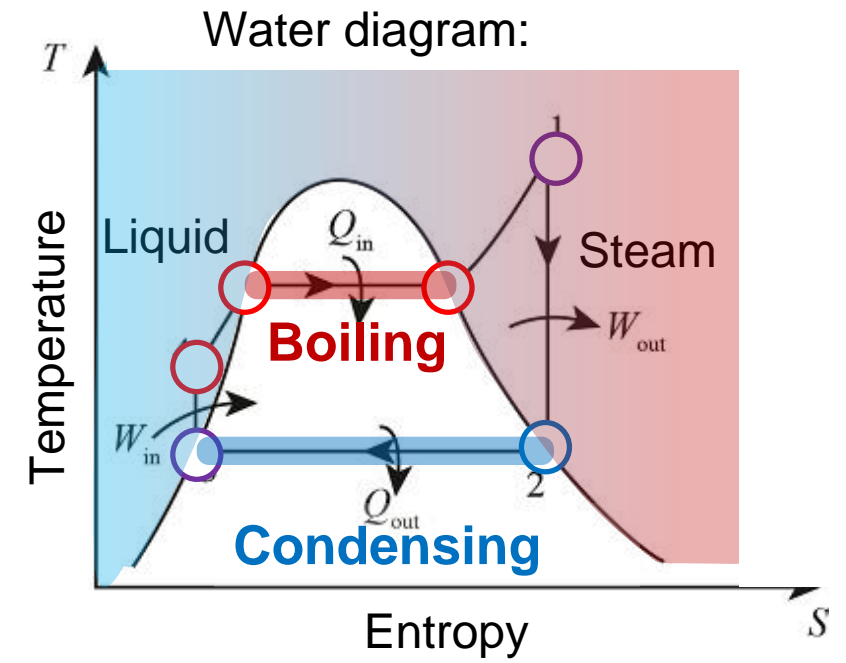
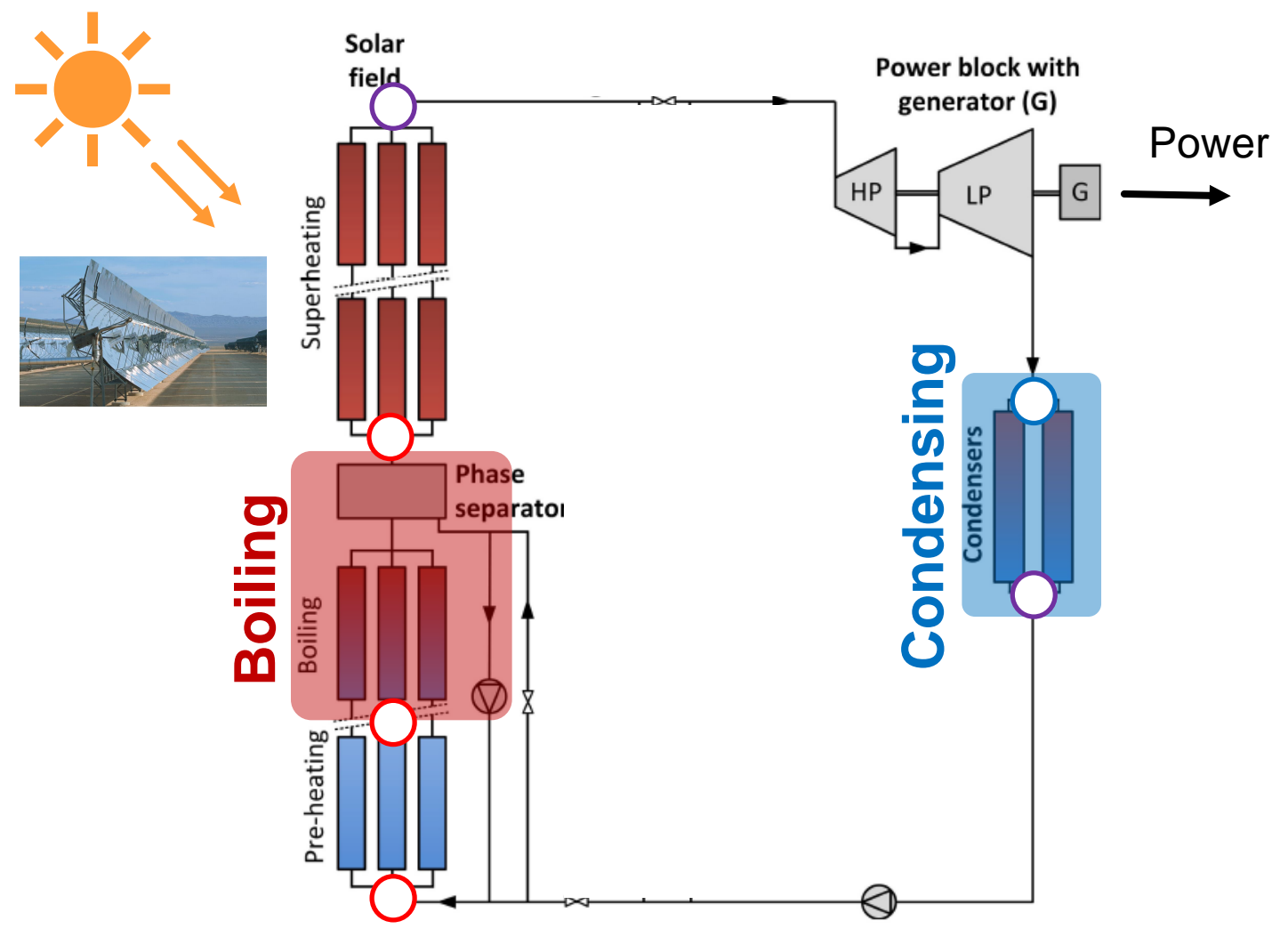
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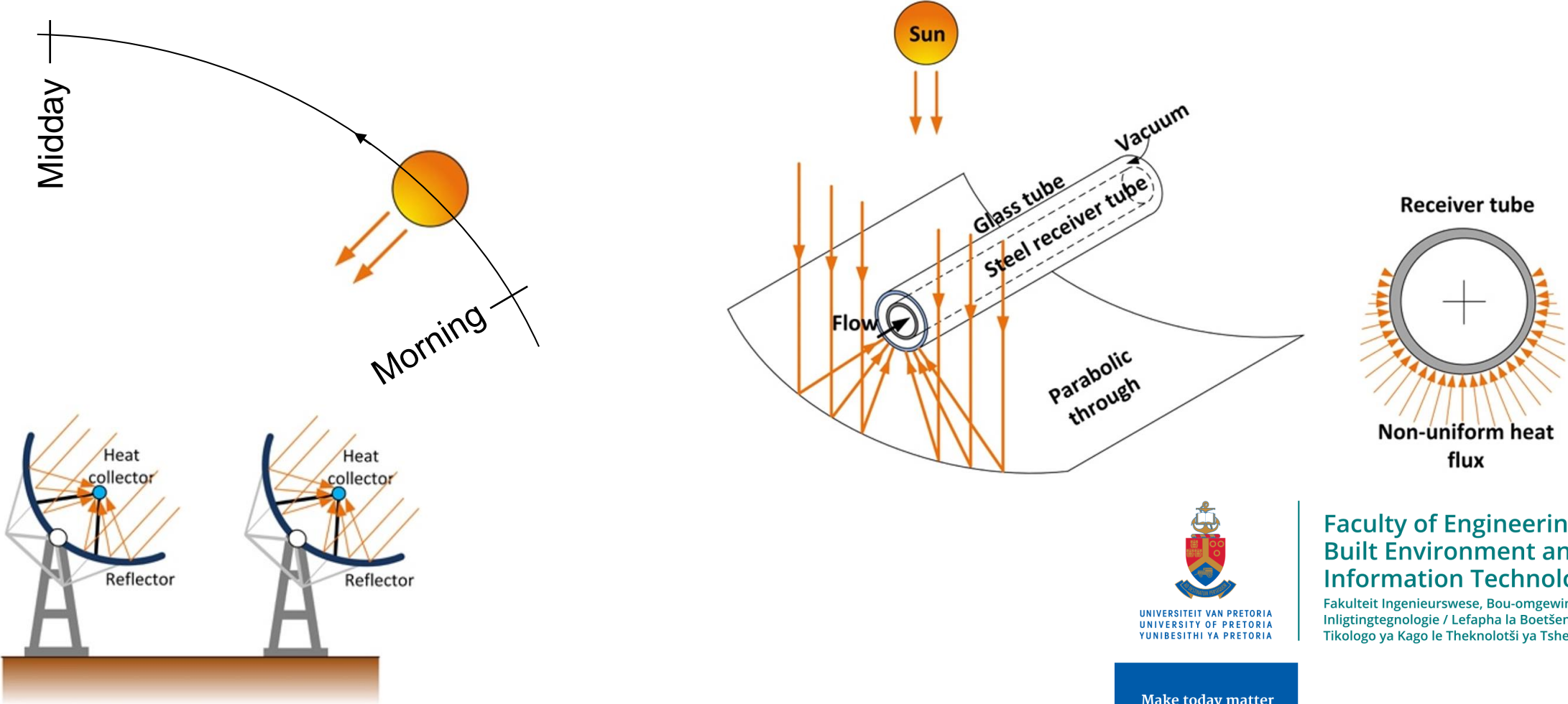
Macro Scale Flow Boiling

Concentrated Solar Power: Direct Steam Generation



Macro Scale Flow Boiling

Concentrated Solar Power: Direct Steam Generation



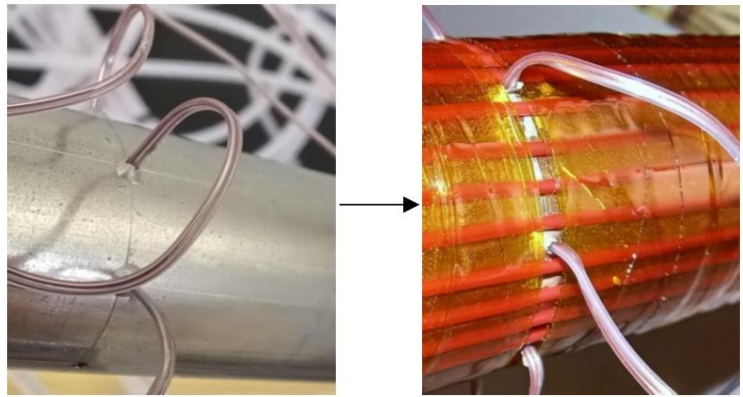
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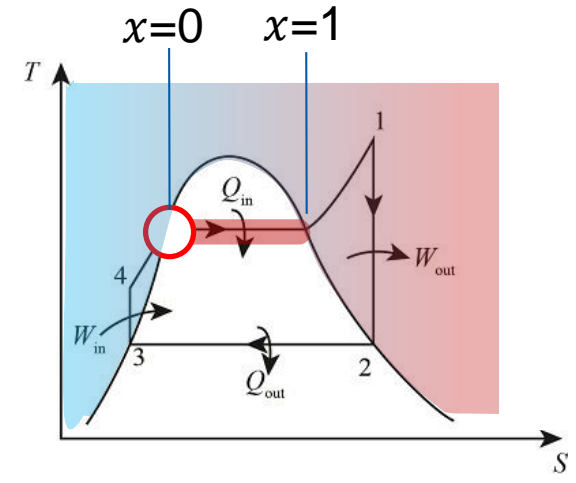
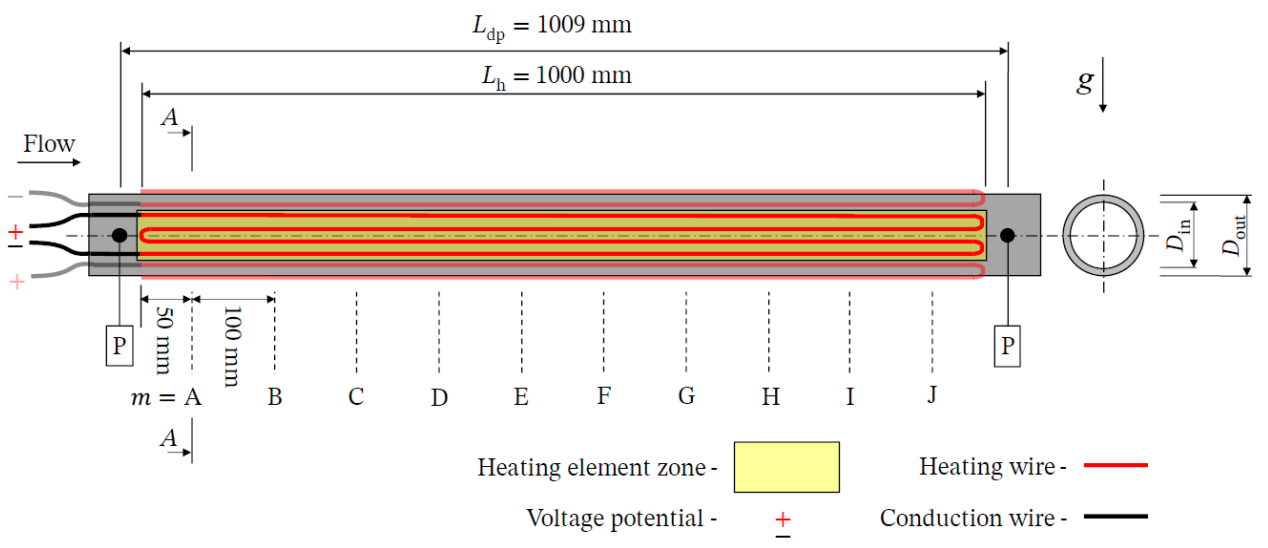
Macro Scale Flow Boiling

Direct Steam Generation: Lab reproduction



(a)

(b)

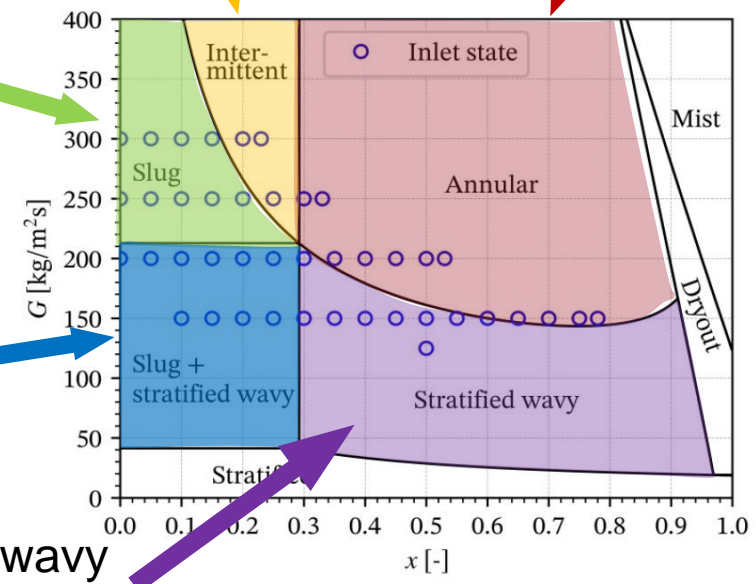
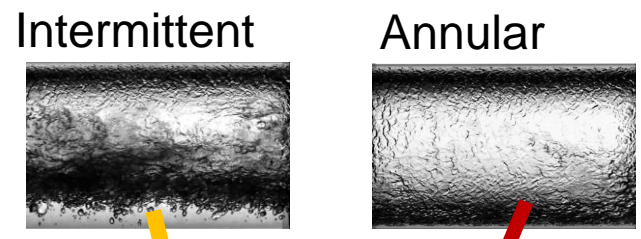


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Macro Scale Flow Boiling

Direct Steam Generation: Flow patterns

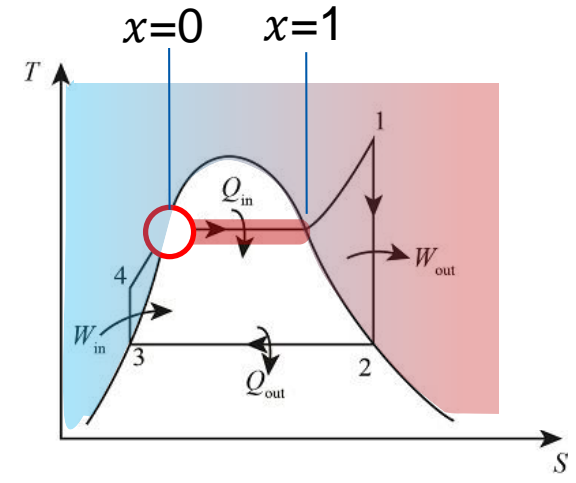


Slug + stratified wavy

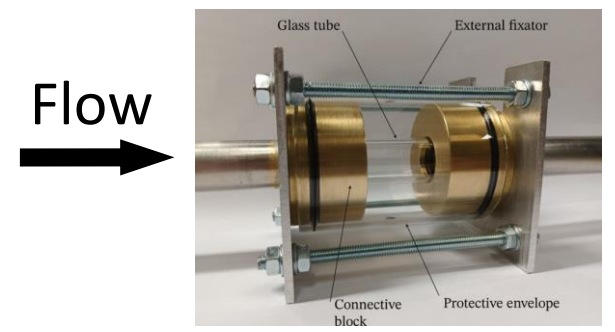
Stratified wavy

More vapour

Faster flow



Sight-glass



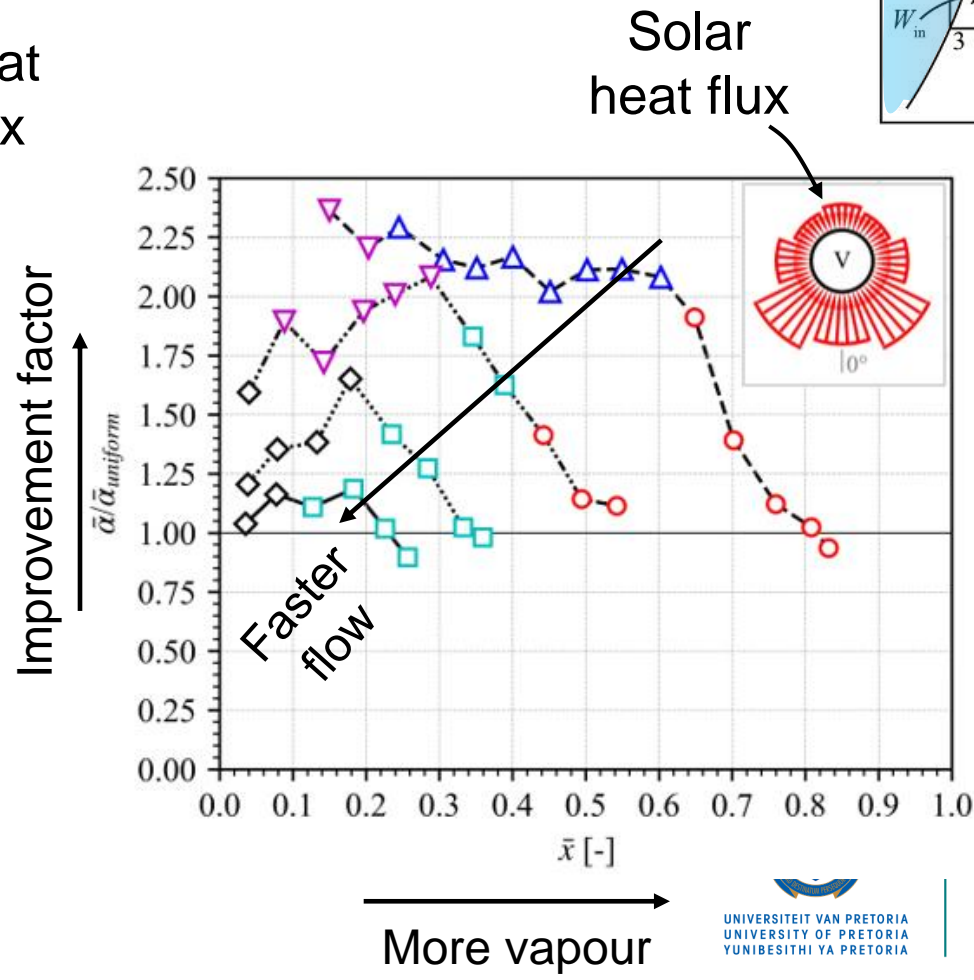
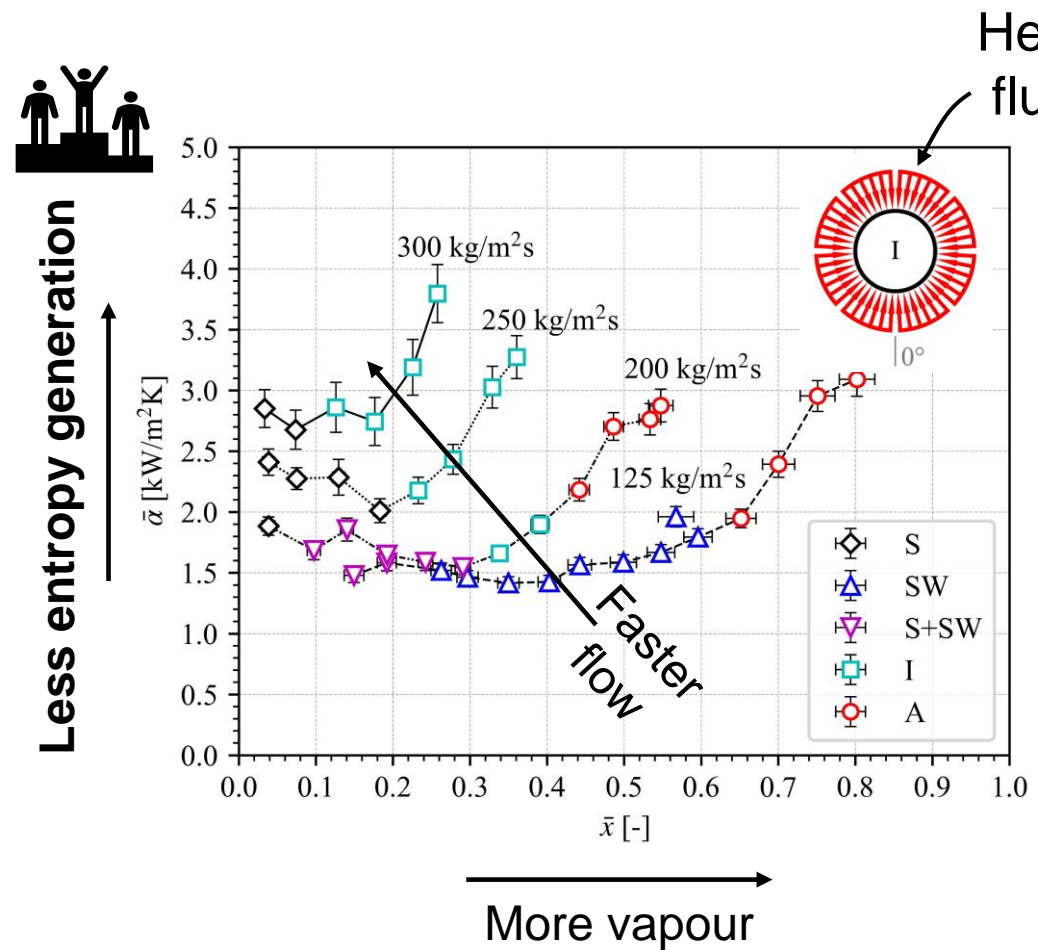
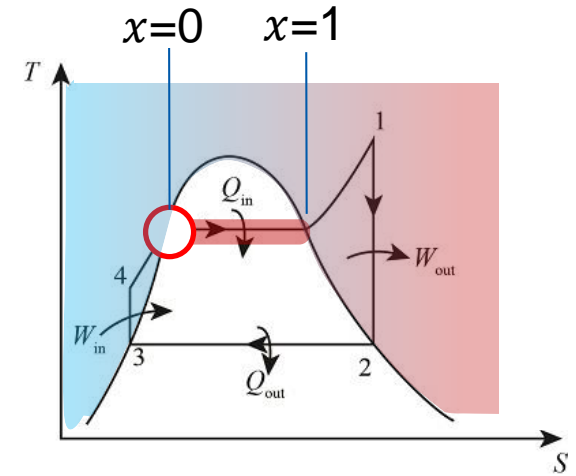
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Macro Scale Flow Boiling

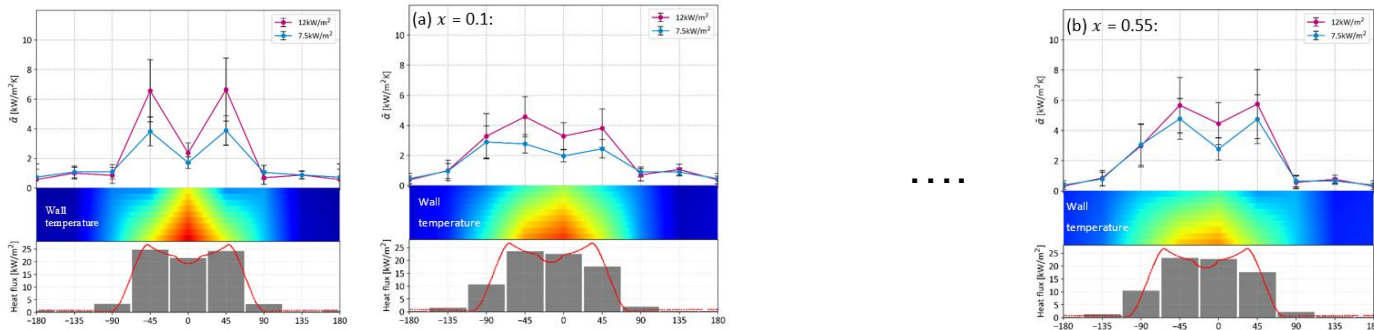
Direct Steam Generation: Heat flux distribution



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Macro Scale Flow Boiling

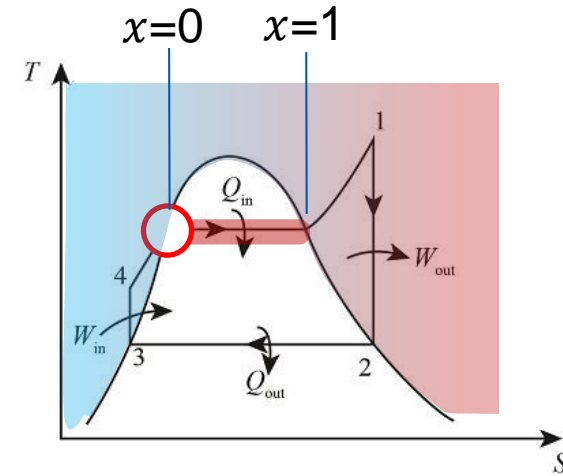
Direct Steam Generation: Solar time



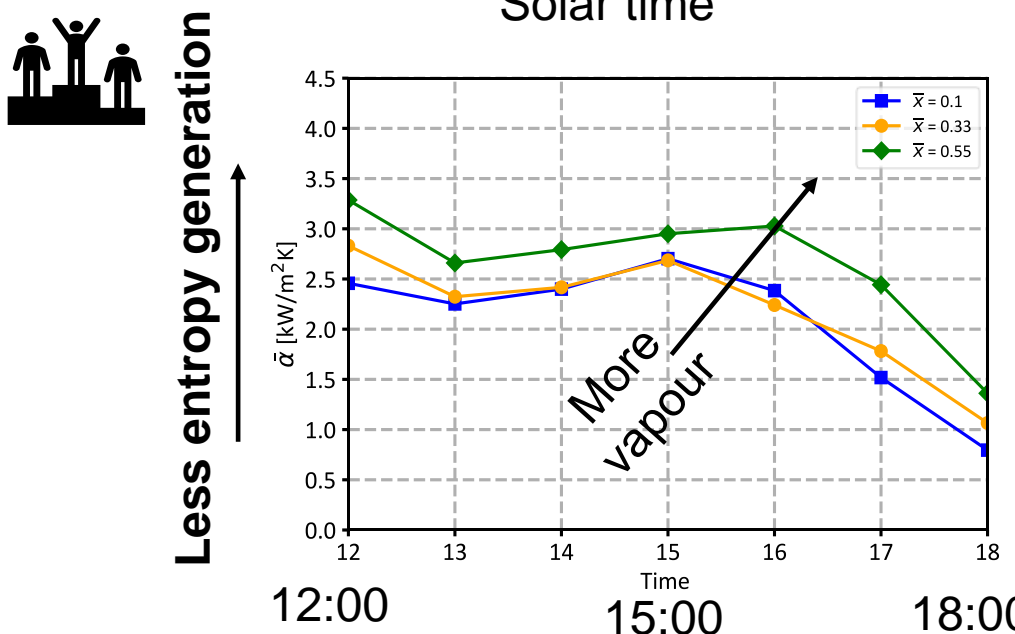
Thermal performance

2D wall temperatures

Solar radiation



Solar time →



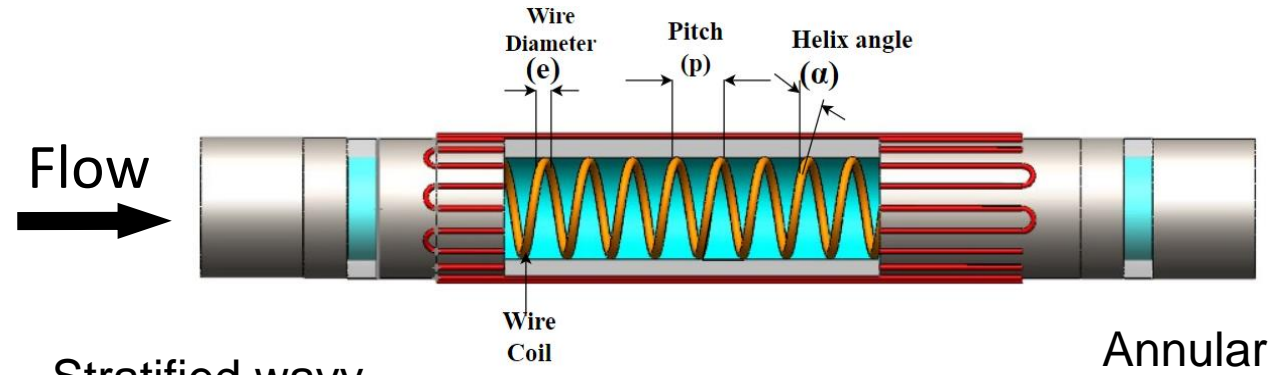
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Macro Scale Flow Boiling

Manipulating the flow pattern

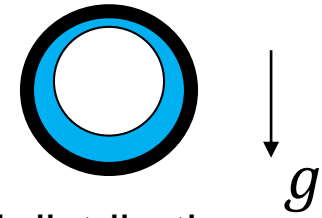
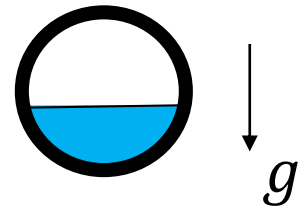


Stratified wavy



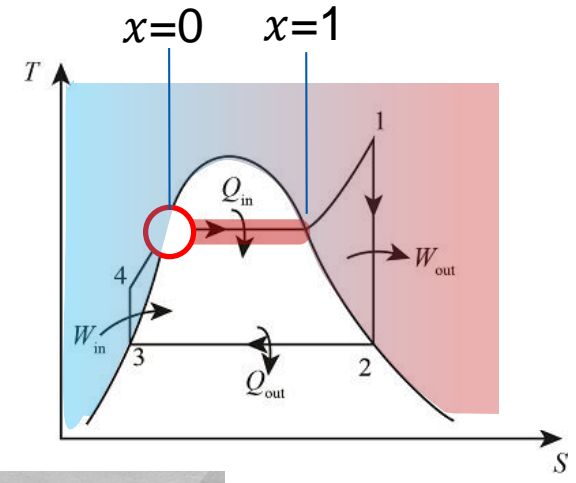
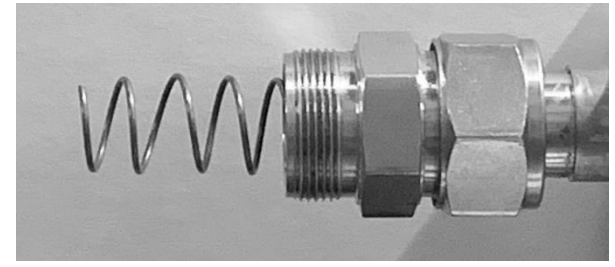
Centrifugal forces

Annular



Liquid distribution around circumference

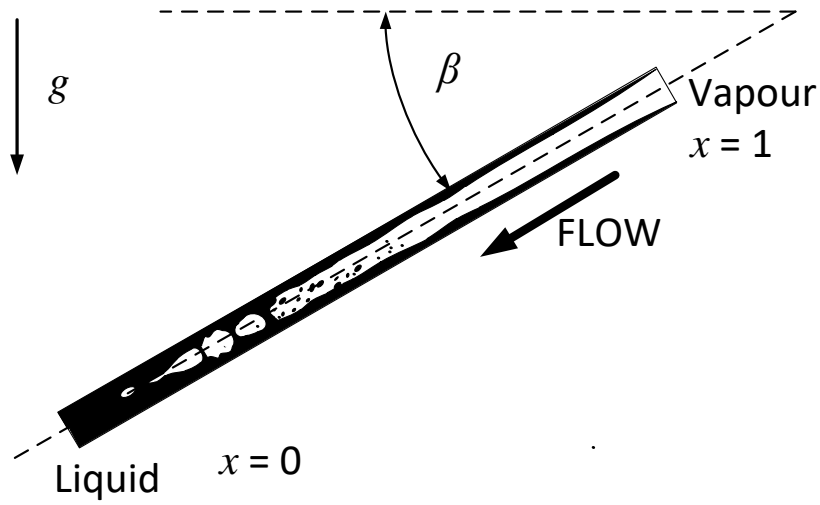
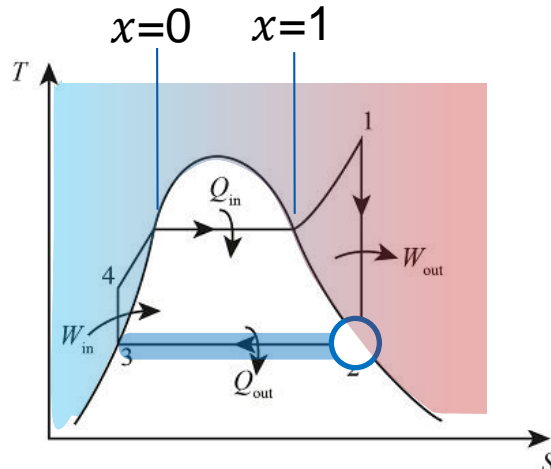
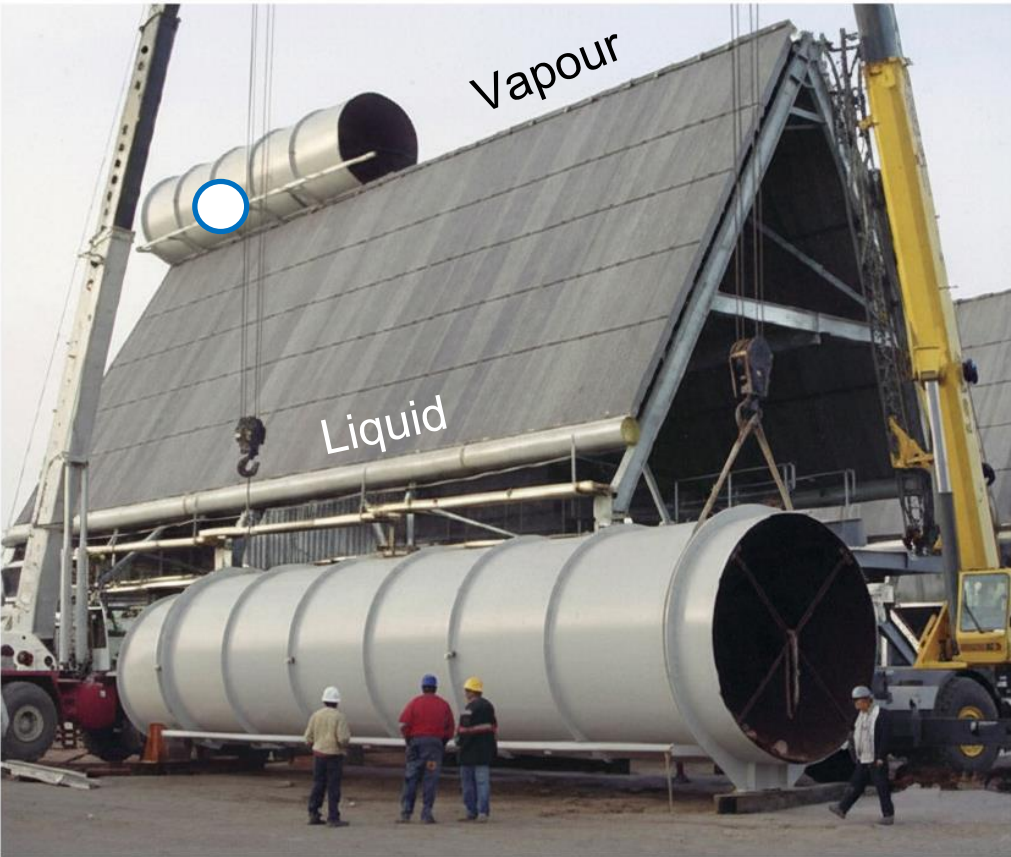
Spiral insert



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Macro Scale Condensation

Air-cooled condensers

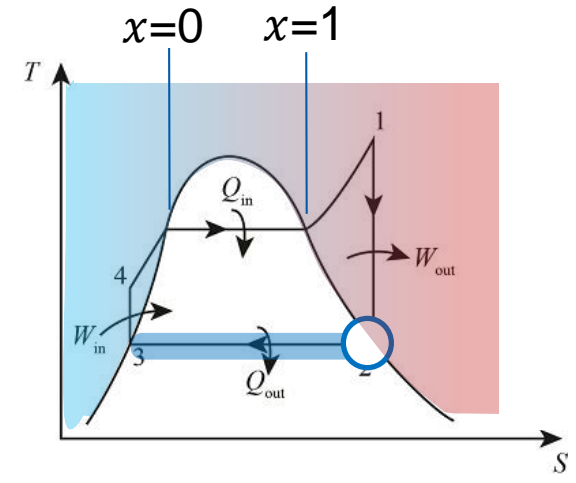
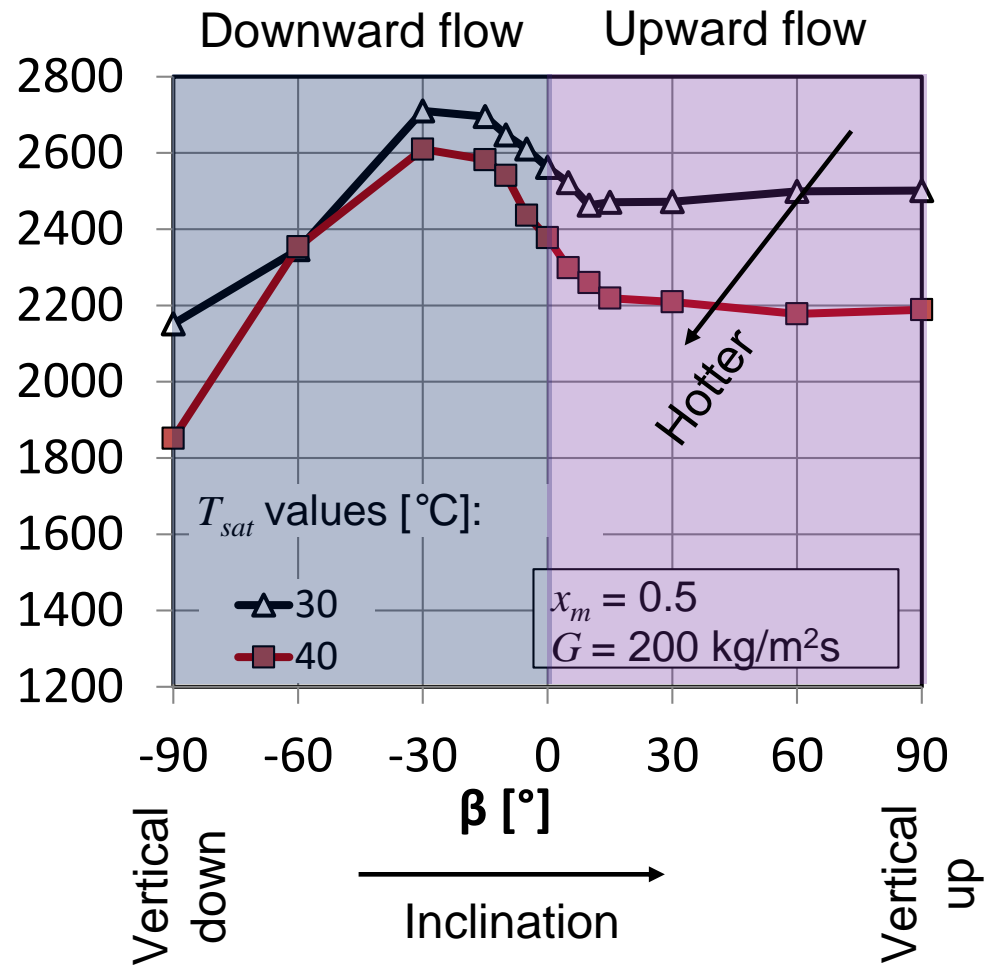


Macro Scale Condensation

Effect of angle



Less entropy generation
↑
 α [W/m²K]



Flow friction?



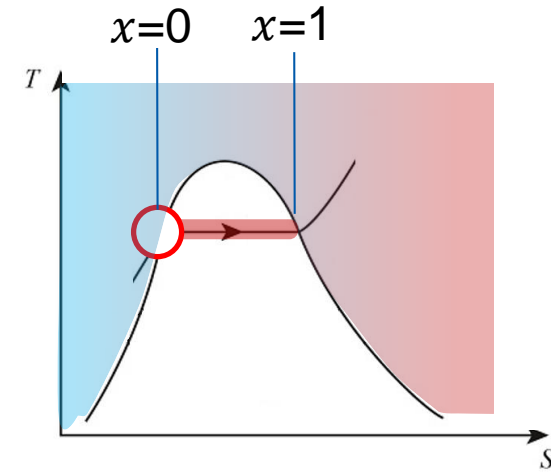
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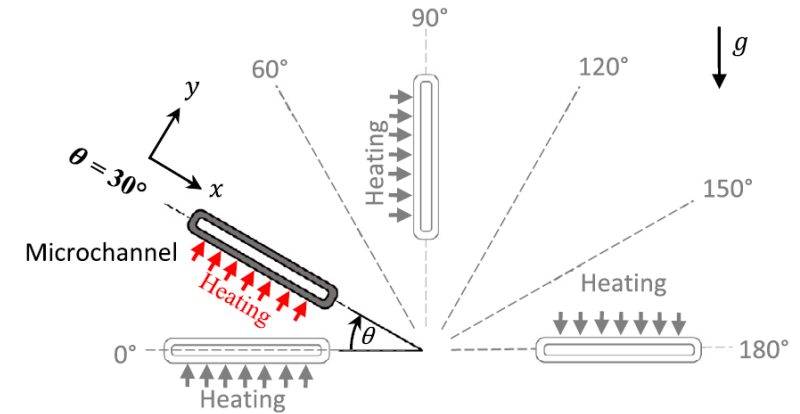
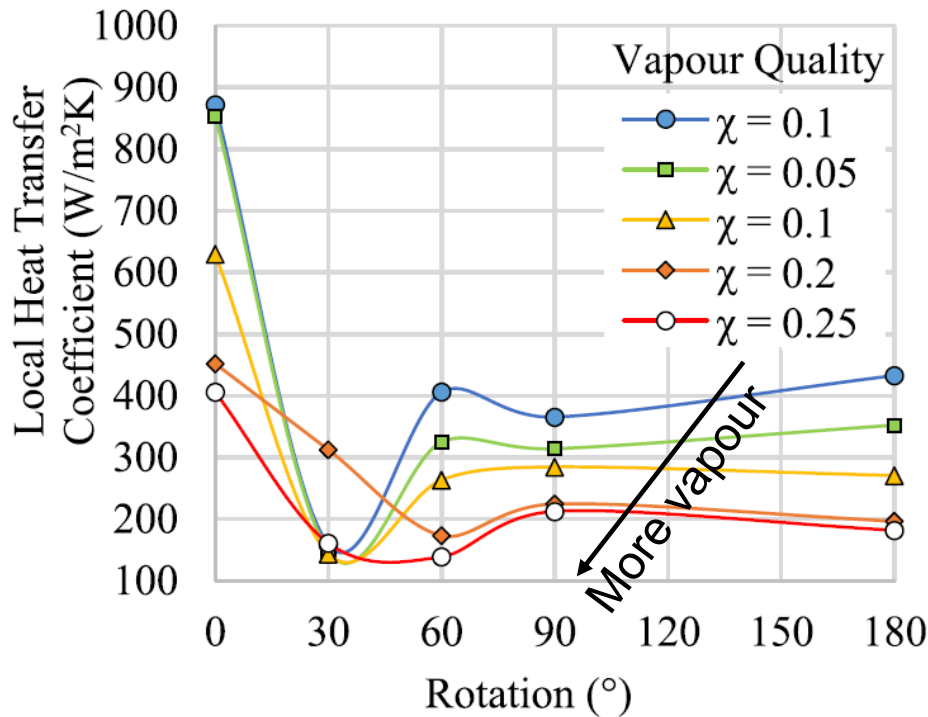
Miniature Scale Flow Boiling

Microchannel (< 500µm)

Flow pattern (playback speed= x0.1)



Less entropy generation ↑



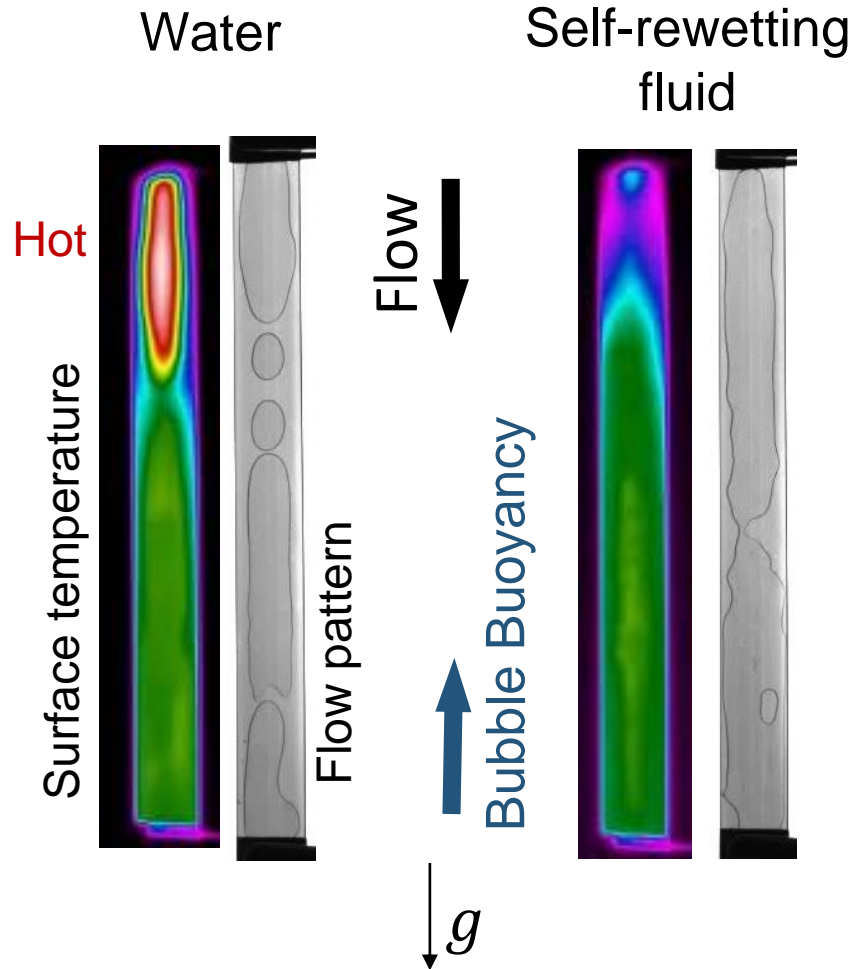
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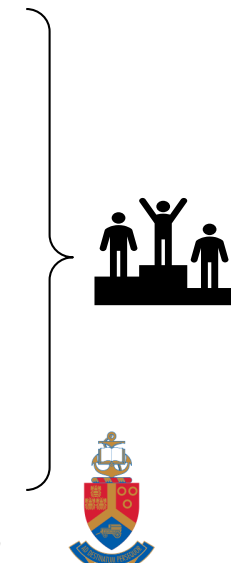
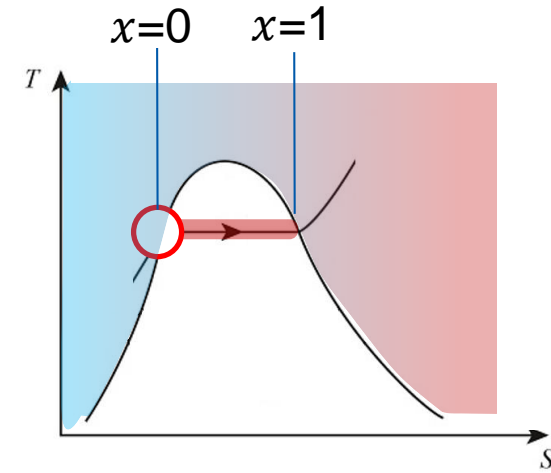
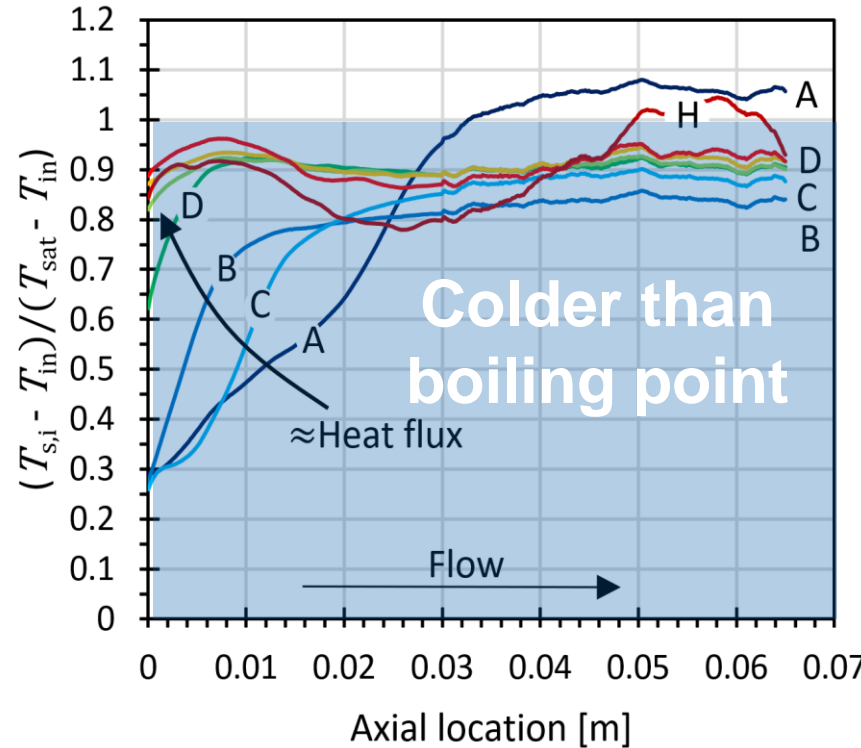
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Miniature Scale Flow Boiling

Microchannels: Surface tension effects



Self-wetting surface temperatures

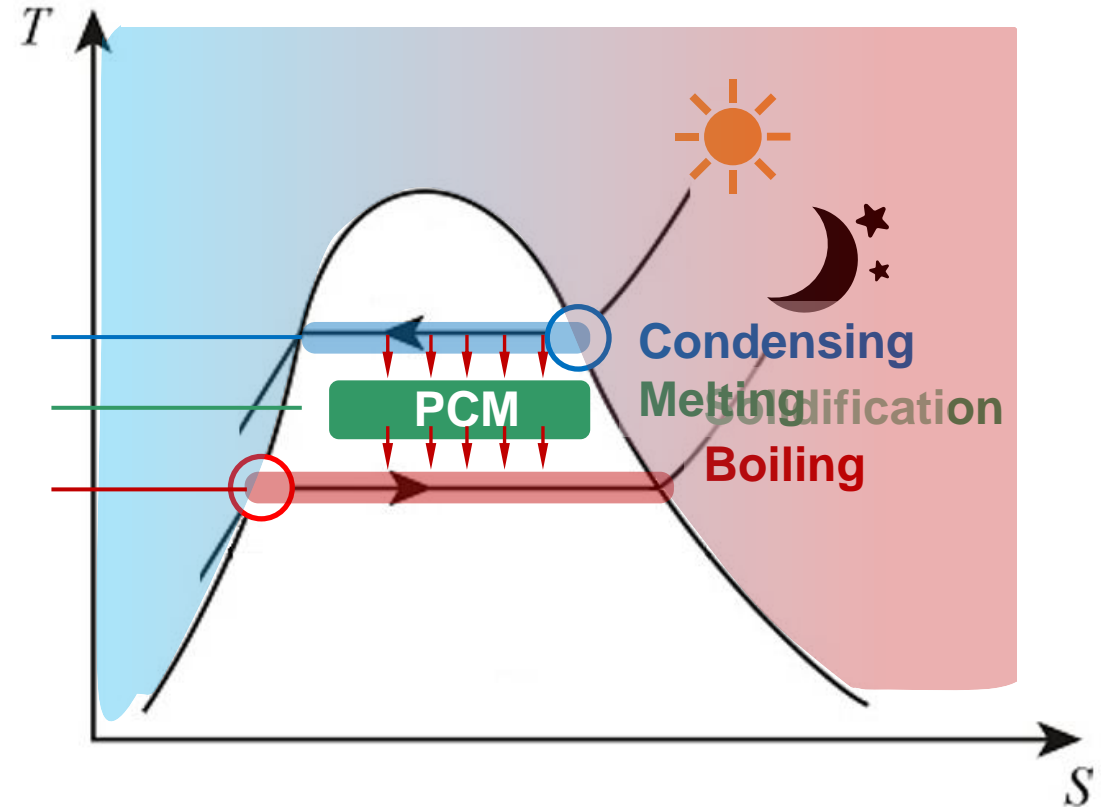
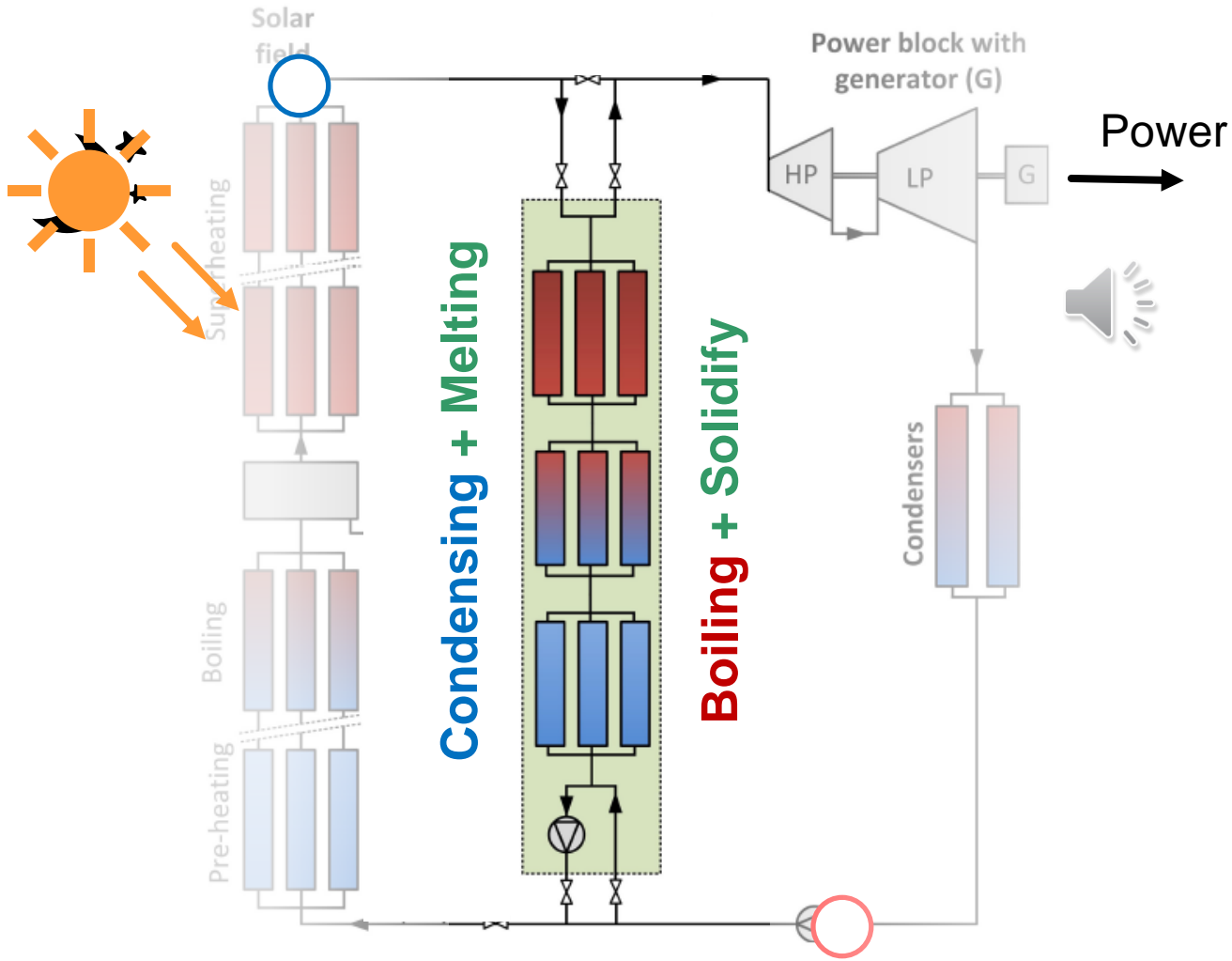


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High-Temperature Thermal Storage

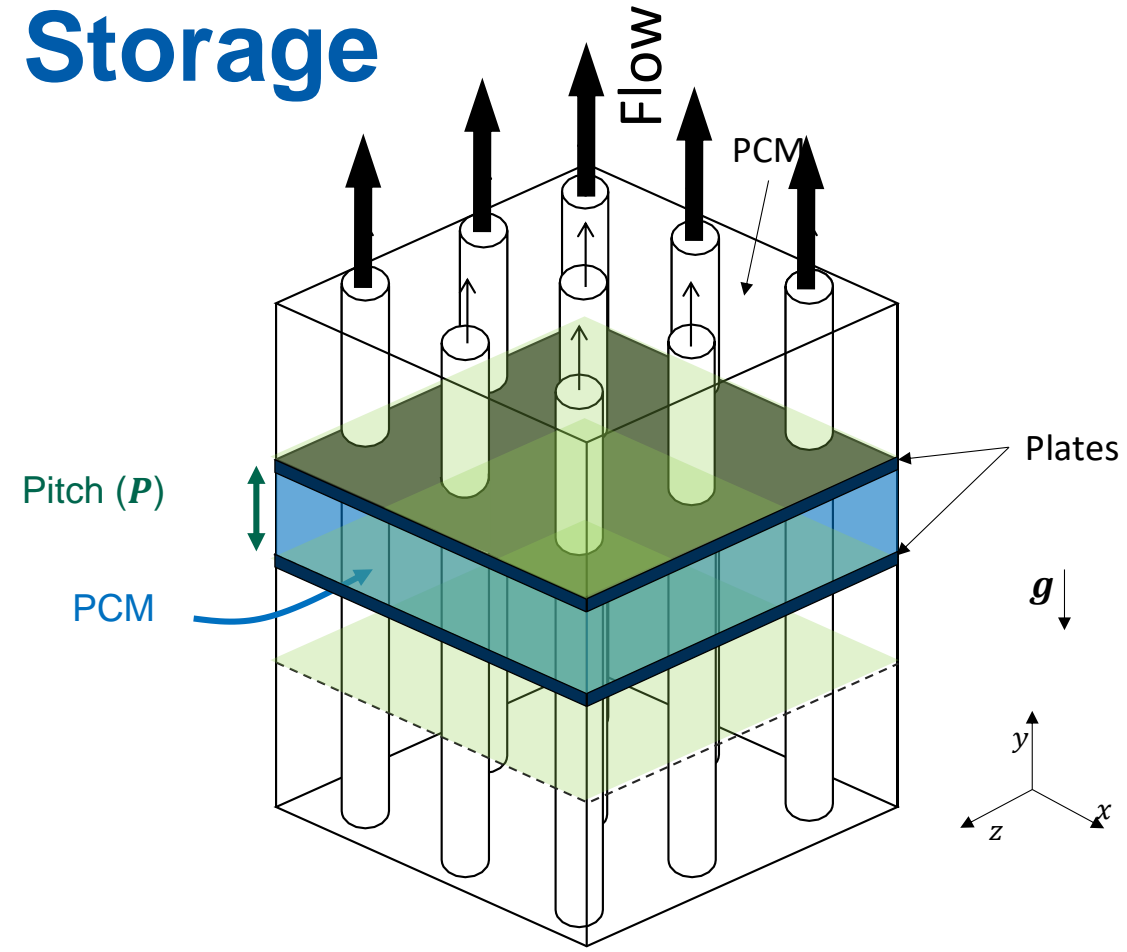
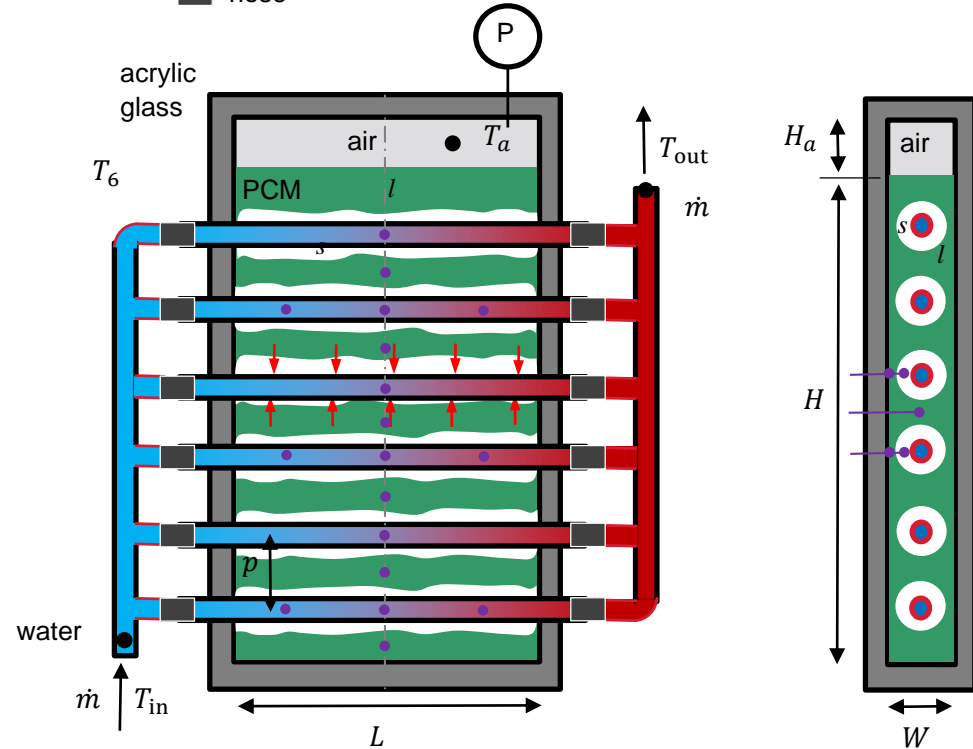
Direct steam generation power production Overview



High-Temperature Thermal Storage

Direct steam generation PCM Energy storage modules

- tube wall / general
- PCM
- ▬ copper tube
- ▬ hose



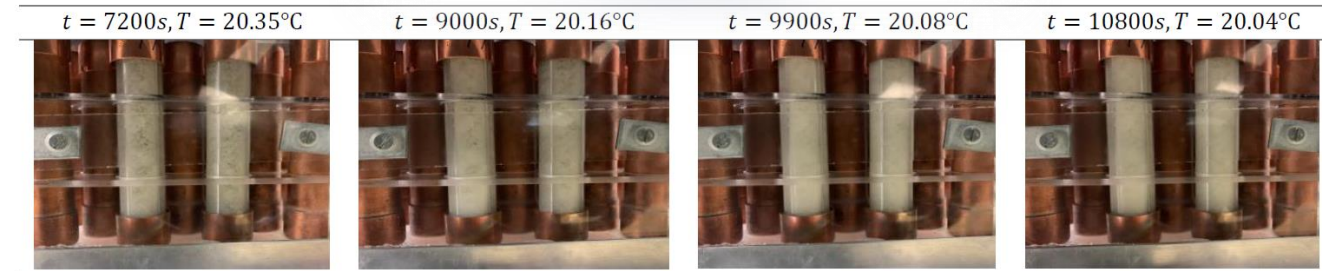
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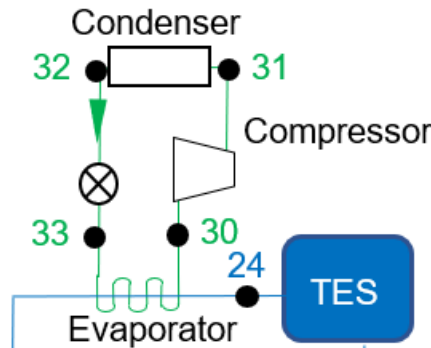
Medium-Temperature Thermal Storage

Semi-passive → net-zero

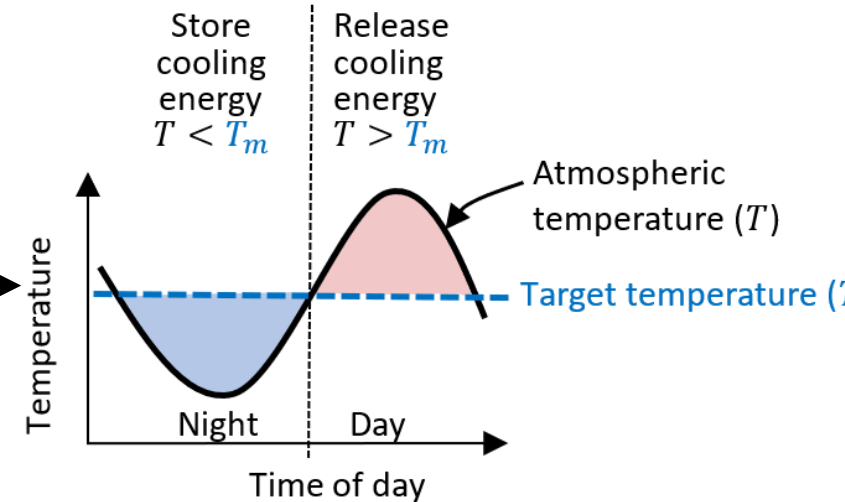
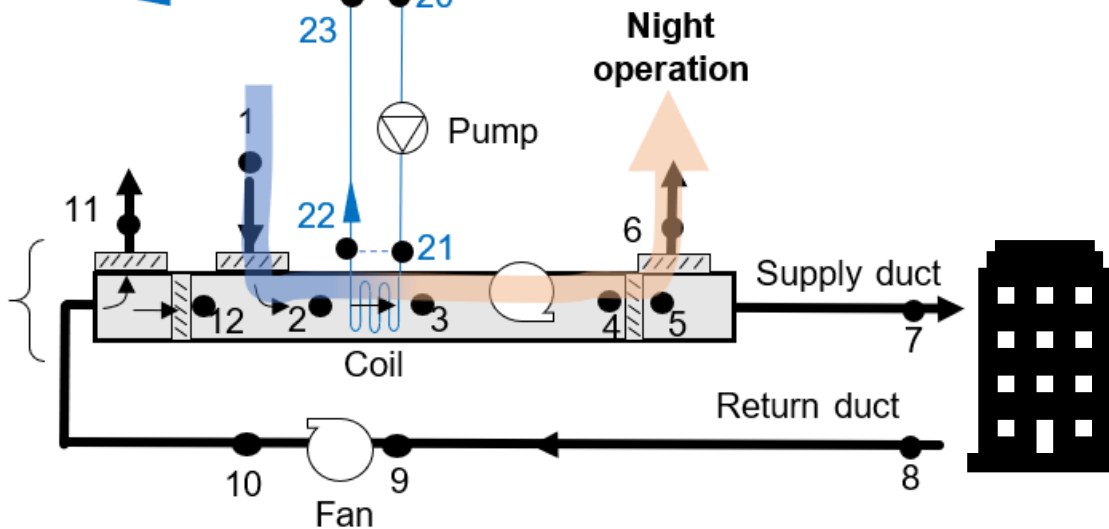
Thermal battery cell



Solidification

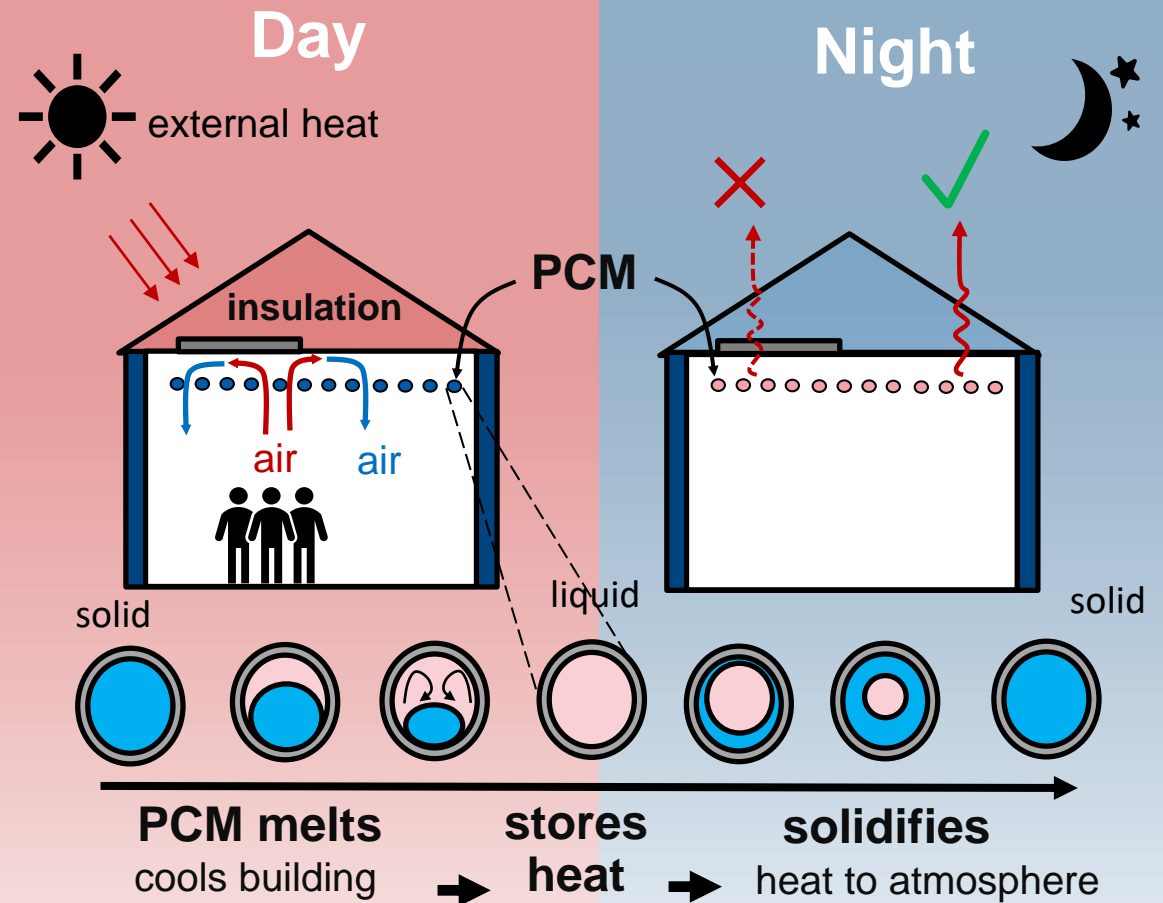
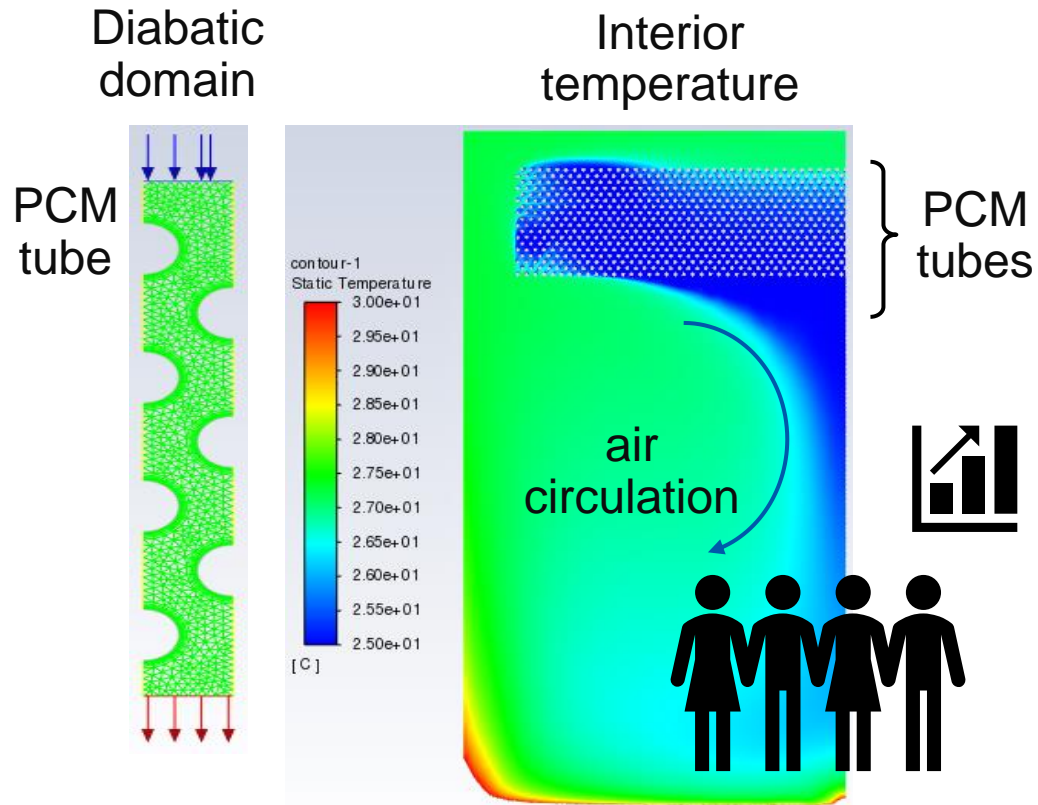


Thermal battery



Medium-Temperature Thermal Storage

Fully-passive → net-zero



Summary

Net zero carbon and net zero energy



Active heat transport

- Direct steam generation power production
- Electronic cooling



Passive thermal storage

- High-temperature 24/7 operation
- Medium-temperature thermal regulation

Image credit: Prof Richard J. Weller
<http://atlas-for-the-end-of-the-world.com>



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Closure

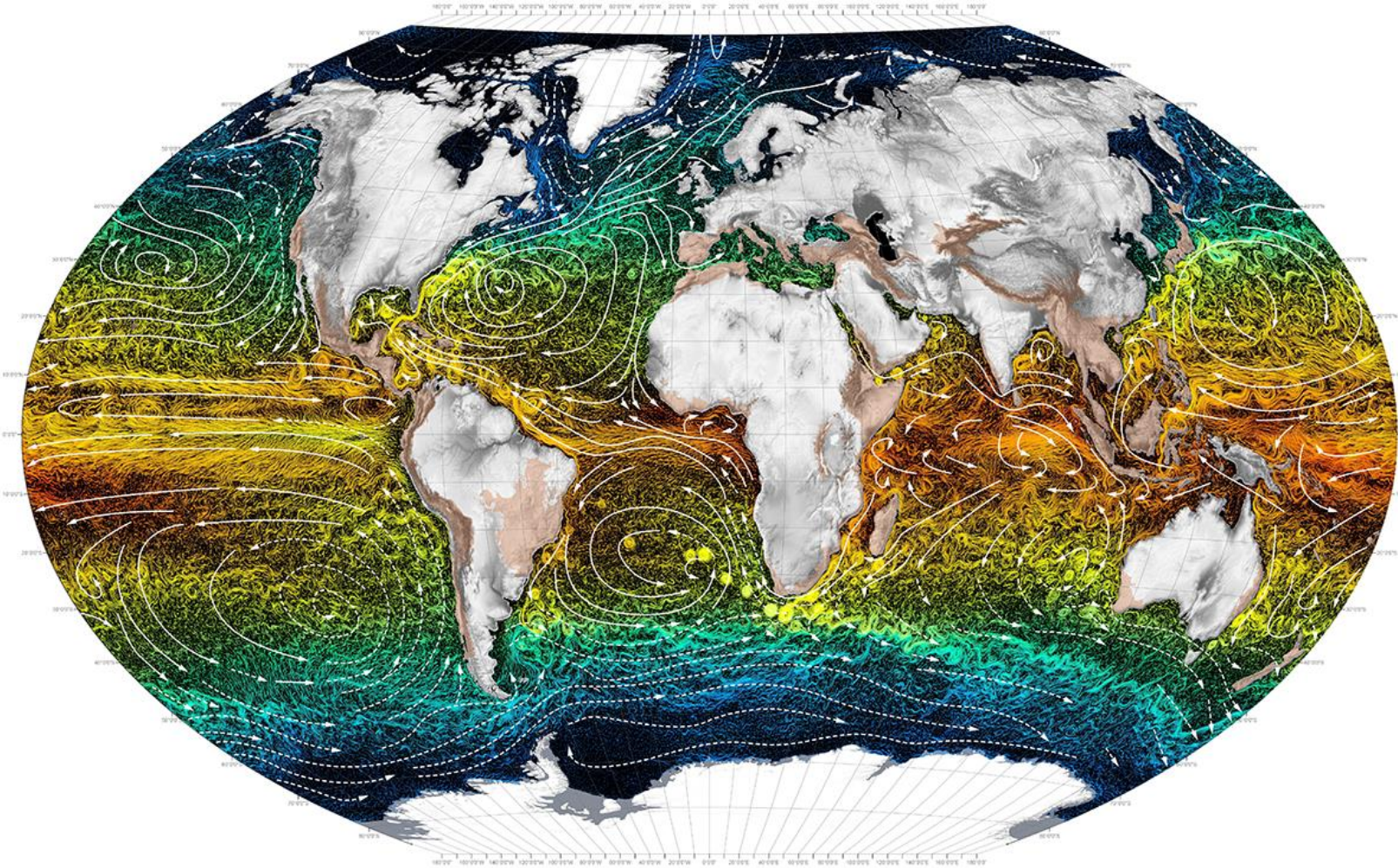


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